Handbook of Ichthyology

Song Flanagan

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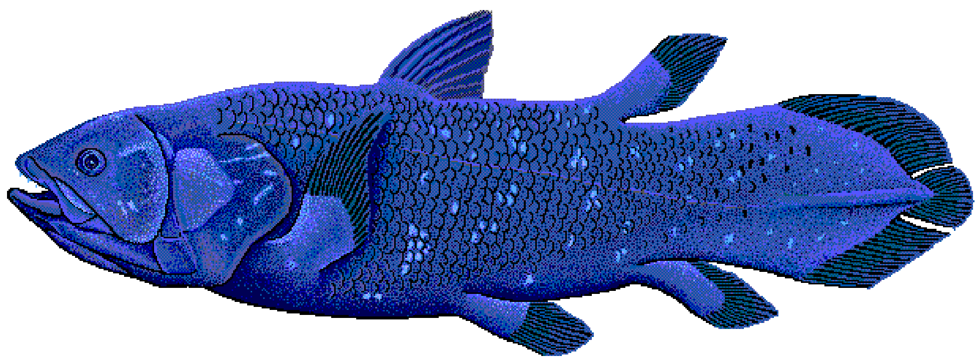
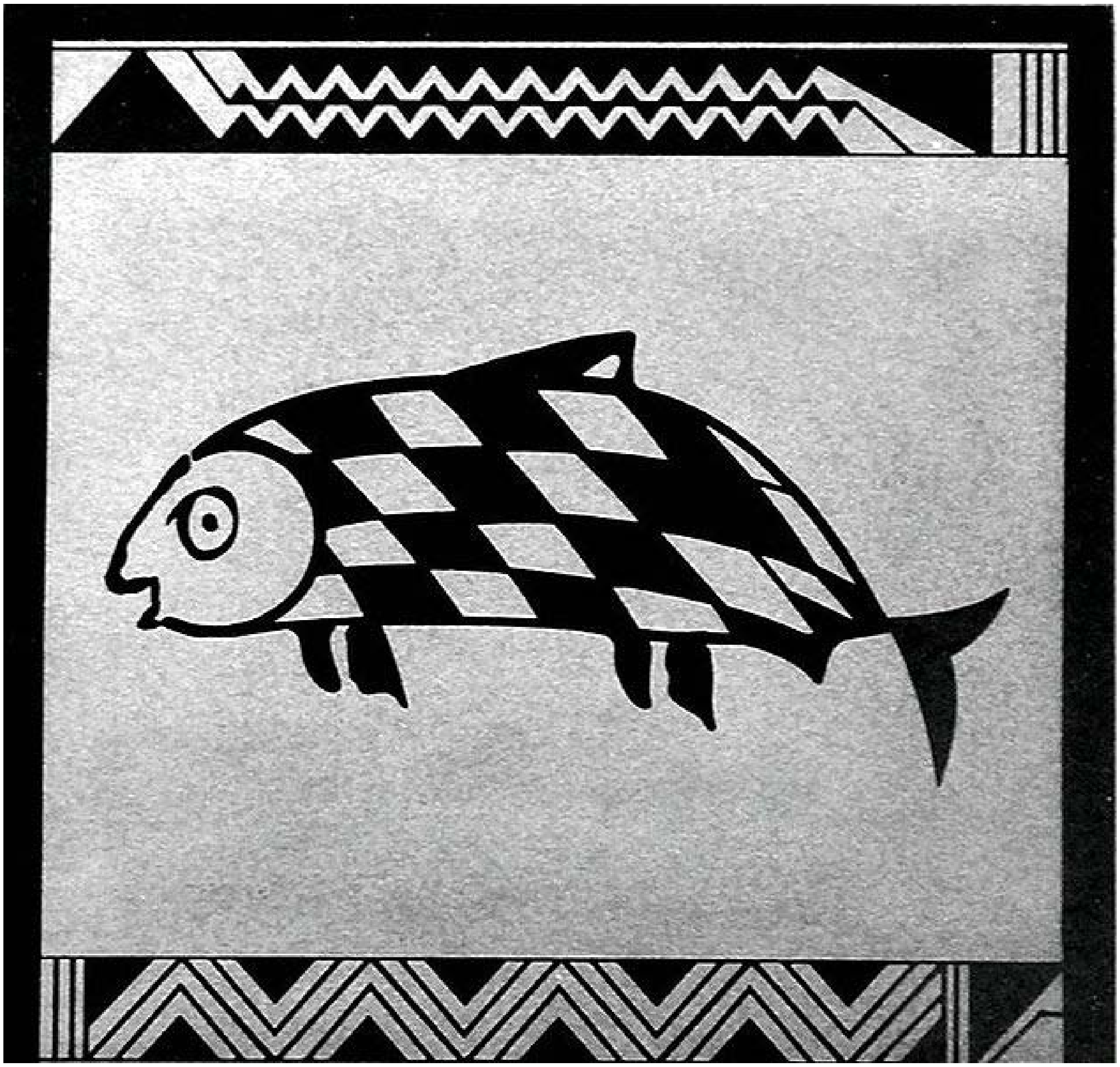
Ichthyology



Ichthyology (from Greek: ἰχθύς, *ikhthus*, "fish"; and λόγος, *logos*, "study") is the branch of zoology devoted to the study of fish. This includes skeletal fish (Osteichthyes), cartilaginous fish (Chondrichthyes), and jawless fish (Agnatha). While a majority of species have probably been discovered and described, approximately 250 new species are officially described by science each year. According to FishBase, 31,500 species of fish had been described by January 2010. There are more fish species than the combined total of all other vertebrates: mammals, amphibians, reptiles and birds.

The practice of ichthyology is associated with marine biology, limnology and fisheries science.

History



Fish represent approximately 8% of all figurative depictions on Mimbres pottery.

The study of fish dates from the Upper Paleolithic Revolution (with the advent of 'high culture'). The science of ichthyology was developed in several interconnecting epochs, each with various significant advancements.

The study of fish receives its origins from human's desire to feed, clothe, and equip themselves with useful implements. According to Michael Barton, a prominent ichthyologist and professor at Centre College, "the earliest ichthyologists were hunters and gatherers who had learned how to obtain the most useful fish, where to obtain them in abundance, and at what times they might be the most available". Early cultures manifested these insights in abstract and identifiable artistic expressions.

1500 BC–40 AD

Informal, scientific descriptions of fish are represented within the Judeo-Christian tradition. The kashrut forbade the consumption of fish without scales or appendages. Theologians and ichthyologists speculate that the apostle Peter and his contemporaries harvested the fish that are today sold in modern industry along the Sea of Galilee, presently known as Lake Kinneret. These fish include cyprinids of the genus *Barbus* and *Mirogrex*, cichlids of the genus *Sarotherodon*, and *Mugil cephalus* of the family Mugilidae.

335 BC–80 AD

Aristotle incorporated ichthyology into formal scientific study. Between 335 BC–322 BC, he provided the earliest taxonomic classification of fish, accurately describing 117 species of Mediterranean fish. Furthermore, Aristotle documented anatomical and behavioral differences between fish and marine mammals. After his death, some of his pupils continued his ichthyological research. Theophrastus, for example, composed a treatise on amphibious fish. The Romans, although less devoted to science, wrote extensively about fish. Pliny the Elder, a notable Roman naturalist, compiled the ichthyological works of indigenous Greeks, including verifiable and ambiguous peculiarities such as the sawfish and mermaid respectively. Pliny's documentation was the last significant contribution to ichthyology until the European Renaissance.

European Renaissance

The writings of three sixteenth century scholars, Hippolyte Salviani, Pierre Belon, and Guillaume Rondelet, signify the conception of modern ichthyology. The investigations of these individuals were based upon actual research in comparison to ancient recitations. This property popularized and emphasized these discoveries. Despite their prominence, Rondelet's *De Piscibus Marinum* is regarded as the most influential, identifying 244 species of fish.

16th–17th century

The incremental alterations in navigation and shipbuilding throughout the Renaissance marked the commencement of a new epoch in ichthyology. The Renaissance culminated with the era of exploration and colonization, and upon the cosmopolitan interest in navigation came the specialization in naturalism. Georg Marcgrave of Saxony composed the *Naturalis Brasilae* in 1648. This document contained a description of 100 species of fish indigenous to the Brazilian coastline. In 1686, John Ray and Francis Willughby collaboratively published *Historia Piscium*, a scientific manuscript containing 420 species of fish, 178 of these newly discovered. The fish contained within this informative literature were arranged in a provisional system of classification.

The classification used within the *Historia Piscium* was further developed by Carolus Linnaeus, the "father of modern taxonomy". His taxonomic approach became the systematic approach to the study of organisms, including fish. Linnaeus was a professor at the University of Uppsala and an eminent botanist; however, one of his colleagues, Peter Artedi, earned the title "father of ichthyology" through his indispensable advancements. Artedi contributed to Linnaeus's refinement of the principles of taxonomy. Furthermore, he recognized five additional orders of fish: Malacopterygii, Acanthopterygii, Branchiostegi, Chondropterygii, and Plagiuri. Artedi developed standard methods for making counts and measurements of anatomical features that are modernly exploited. Another associate of Linnaeus, Albertus Seba, was a prosperous pharmacist from Amsterdam. Seba assembled a cabinet, or collection, of fish. He invited Artedi to utilize this assortment of fish; unfortunately, in 1735, Artedi fell into an Amsterdam canal and drowned at the age of 30.

Linnaeus posthumously published Artedi's manuscripts as *Ichthyologia, sive Opera Omnia de Piscibus* (1738). His refinement of taxonomy was culminated subsequent to the development of the binomial nomenclature which is in use by contemporary ichthyologists. Furthermore, he revised the orders introduced by Artedi, placing significance on pelvic fins. Fish lacking this appendage were placed within the order Apodes; fish containing abdominal, thoracic, or jugular pelvic fins were termed Abdominales, Thoracici, and Jugulares respectively. However, these alterations were not grounded within the evolutionary theory. Therefore, it would take over a century until Charles Darwin would provide the intellectual foundation from which we would be permitted to perceive that the degree of similarity in taxonomic features was a consequence of phylogenetic relationship.

Modern era

Close to the dawn of the nineteenth century, Marcus Elieser Bloch of Berlin and Georges Cuvier of Paris made an attempt to consolidate the knowledge of ichthyology. Cuvier summarized all of the available information in his monumental *Histoire Naturelle des Poissons*. This manuscript was published between 1828 and 1849 in a 22 volume series. This documentation contained 4,514 species of fish, 2,311 of these new to science. This piece of literature remains one of the most ambitious treatises of the modern world. The scientific exploration of the Americas progressed our knowledge of the remarkable diversity of fish. Charles Alexandre Lesueur was a student of Cuvier. He made a cabinet of fish dwelling within the Great Lakes and Saint Lawrence River regions.

Adventurous individuals such as John James Audubon and Constantine Samuel Rafinesque figure in the faunal documentation of North America. These persons often traveled with one another and composed *Ichthyologia Ohiensis* in 1820. In addition, Louis Agassiz of Switzerland established his reputation through the study of freshwater fish and organisms and the pioneering of paleoichthyology. Agassiz eventually immigrated to the United States and taught at Harvard University in 1846.

Albert Günther published his *Catalogue of the Fishes of the British Museum* between 1859 and 1870, describing over 6,800 species and mentioning another 1,700. Generally considered one of the most influential ichthyologists, David Starr Jordan wrote 650 articles and books on the subject as well as serving as president of Indiana University and Stanford University.

Modern Publications

Publication	Frequency	Date of Publication	Affiliated Company
Copeia	Quarterly	27 December 1913	American Society of Ichthyologists and Herpetologists
Journal of Applied Ichthyology	Bi-monthly	Unknown	Blackwell Publishing

Organizations

Organizations

- American Elasmobranch Society
- American Fisheries Society
- American Society of Ichthyologists and Herpetologists
- Association of Systematics Collections
- Ichthyological Society of Hong Kong (Chinese: 香港魚類學會)
- Native Fish Conservancy
- Neotropical Ichthyological Association

Organizations

- North American Native Fishes Association
- Panhellenic Society of Technologists Ichthyologists
- Society for Integrative and Comparative Biology
- Society for Northwestern Vertebrate Biology
- Society for the Preservation of Natural History Collections
- Southeastern Fishes Council
- Southwestern Association of Naturalists
- The World Conservation Union

Notable ichthyologists

- Alexander Emanuel Agassiz
- Louis Agassiz
- HIM Emperor Akihito of Japan
- Peter Artedi
- Herbert R. Axelrod
- William O. Ayres, California
- Spencer Fullerton Baird
- Tarleton Hoffman Bean
- Lev Berg, Russia

- Hans C. Bjerring
- Pieter von Bleeker, East Indies
- Marcus Elieser Bloch
- George Albert Boulenger
- Edward Drinker Cope
- Georges Cuvier
- Francis Day, India
- Carl H. Eigenmann
- Rosa Smith Eigenmann
- Samuel Garman
- Charles Henry Gilbert
- Theodore Nicholas Gill
- Charles Frédéric Girard
- George Brown Goode
- Albert Günther
- Carl L. Hubbs
- Erik Jarvik
- David Starr Jordan
- Seth Eugene Meek
- George S. Myers
- John Treadwell Nichols, China, founder of *Copeia*
- John Richardson Norman
- C. Tate Regan
- Donn E. Rosen
- J.L.B. Smith
- Edwin C. Starks
- Franz Steindachner
- Erik Stensiö
- Tom Turner, University of New Mexico
- Achille Valenciennes
- Francis Willughby
- Joshua William Huffman
- Menon Ambat Gopalan Kutty Zoological Survey of India

Chapter- 2

Diversity of Fish

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

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

By species

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

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

Jawless fish

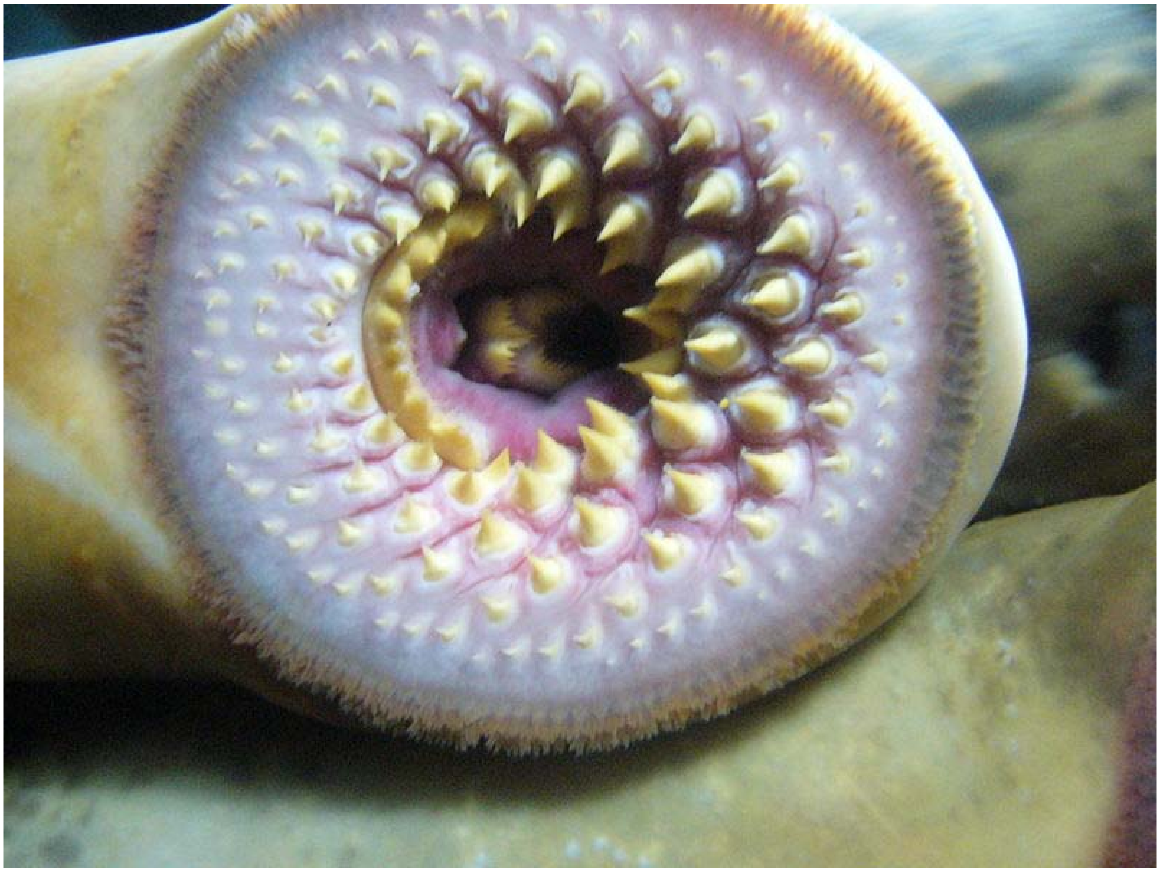
Jawless fish are the most primitive fish. There is current debate over whether these are really fish at all. They have no jaw, no scales, no paired fins, and no bony skeleton. Their skin is smooth and soft to the touch, and they are very flexible. Instead of a jaw, they possess an oral sucker. They use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

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

Stir-fried hagfish, from Korean cuisine

Lampreys attached to a lake trout

Pacific hagfish resting on bottom at 280 m

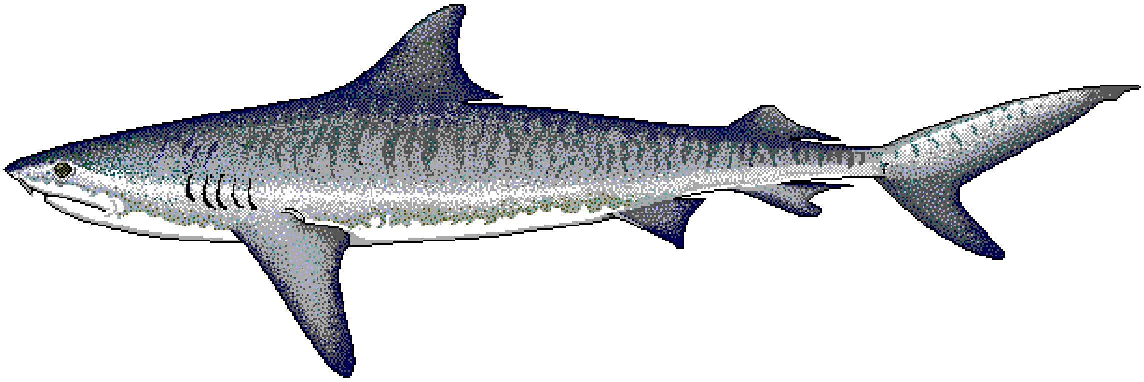


Mouth of a sea lamprey

Cartilaginous fish

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

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



Tiger shark

Whale shark

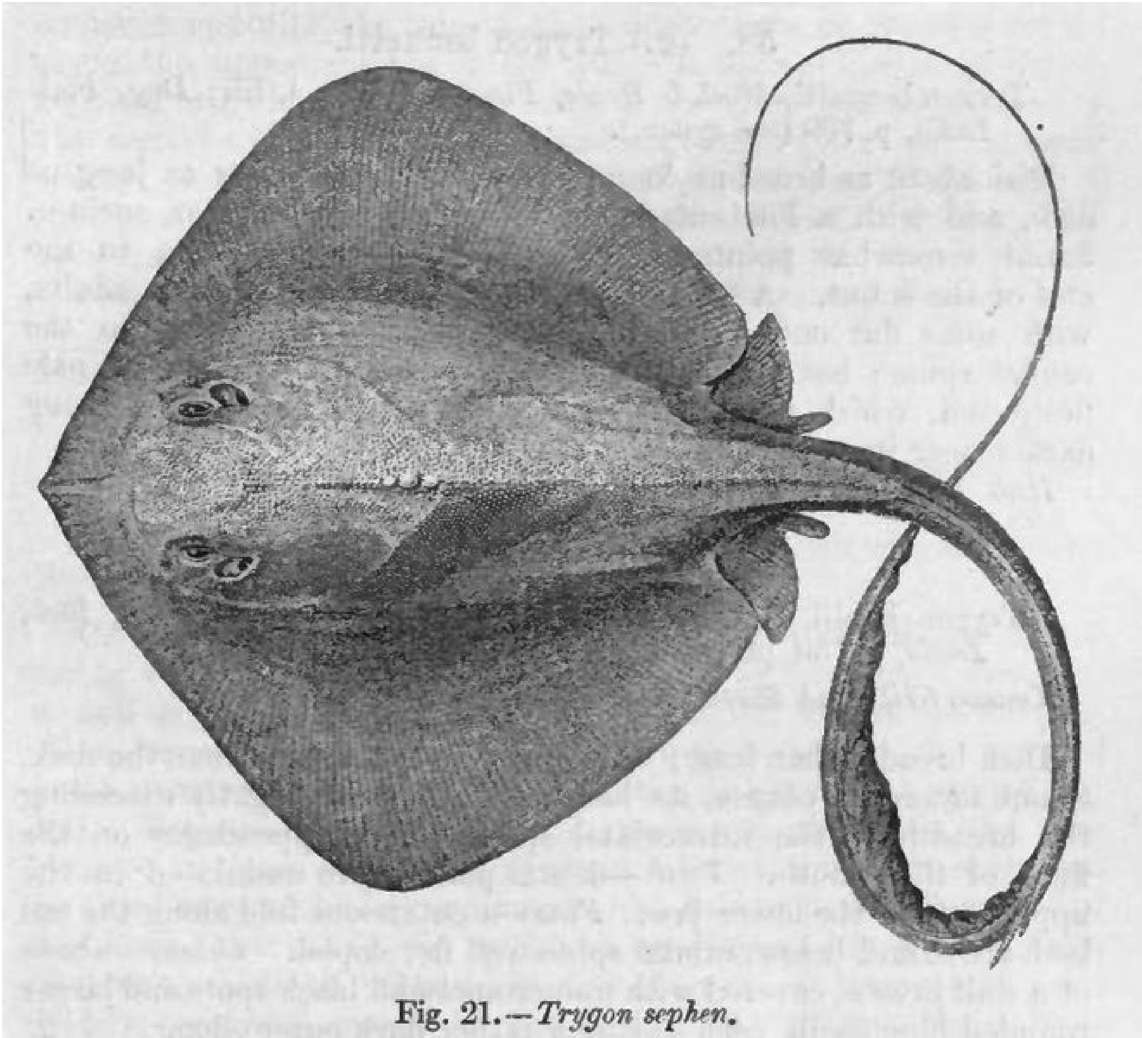
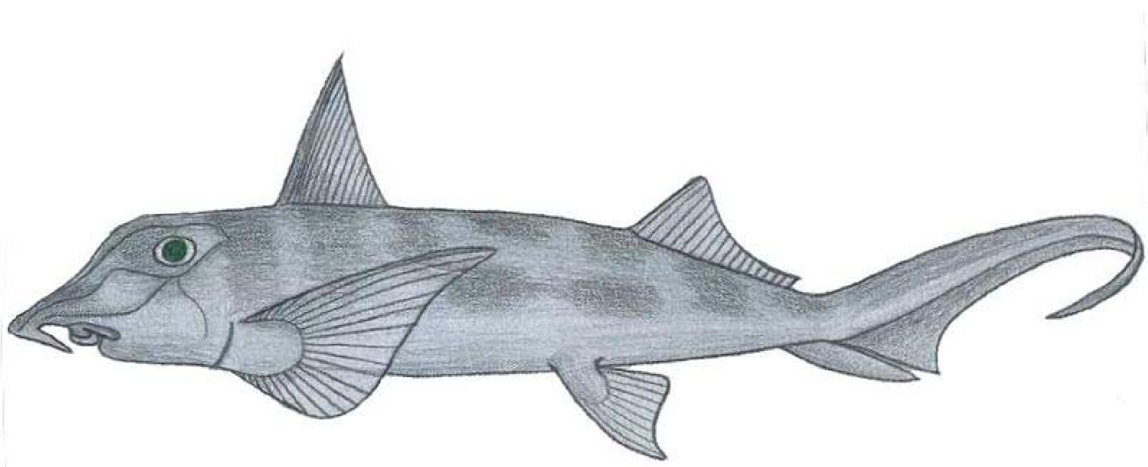


Fig. 21.—*Trygon sephen.*

Stingray



This elephant fish is a chimaera

Bony fish

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

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

Lungfish can breathe in air as well as water

This Atlantic sturgeon is a chondrostean

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

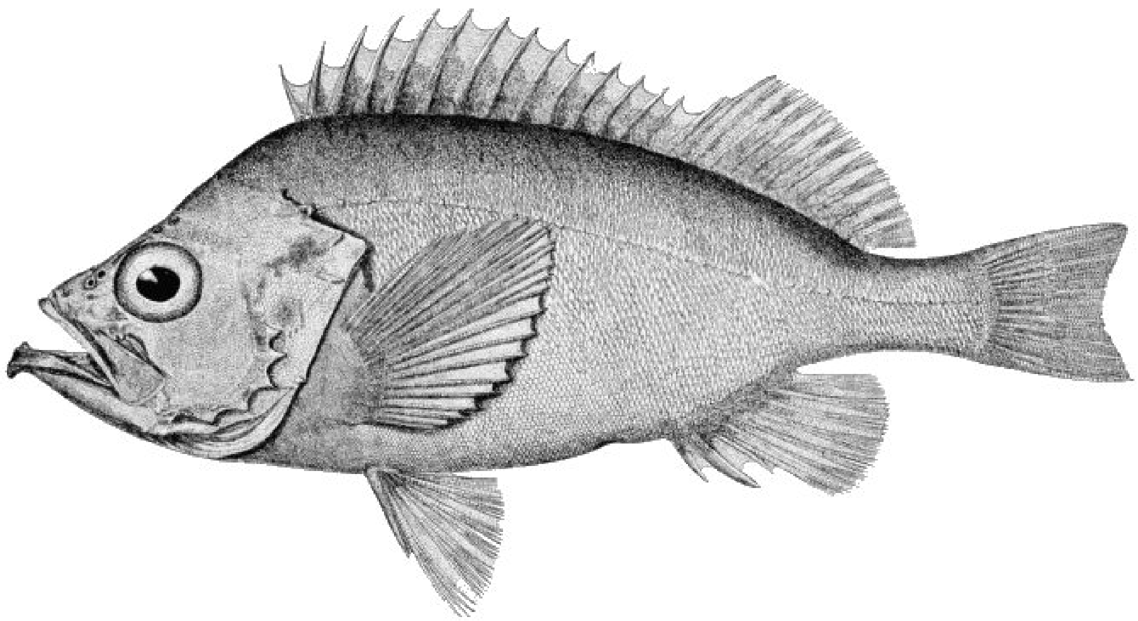
This bowfin is a holostean

Teleosts

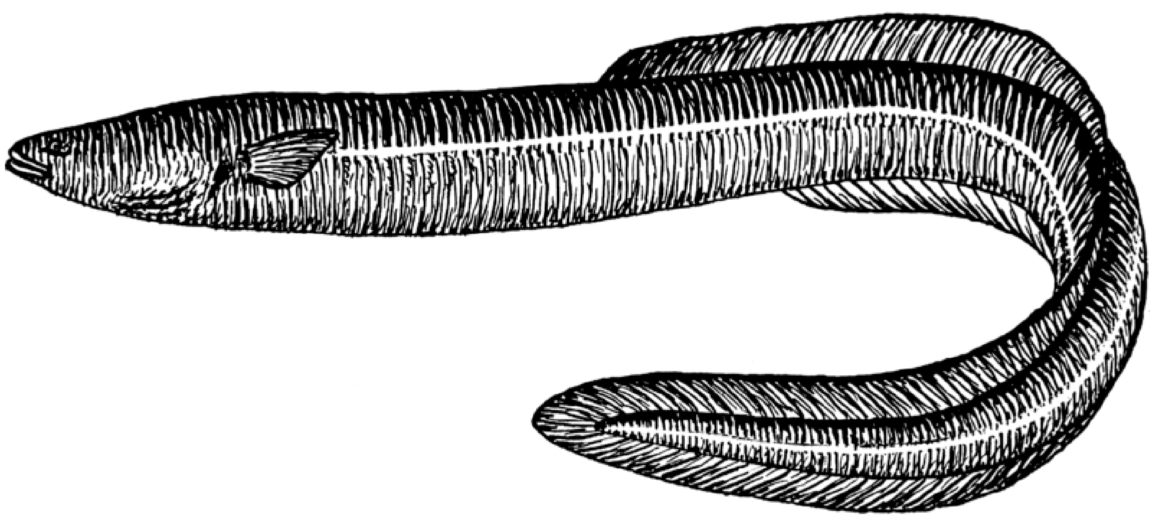
Teleosts are the most advanced or "modern" fishes. They are overwhelmingly the dominant class of fishes (or for that matter, vertebrates) with nearly 30,000 species, covering about 96 percent of all extant fish species. They are ubiquitous throughout fresh water and marine environments from the deep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

Teleosts have a movable maxilla and premaxilla and corresponding modifications in the jaw musculature. These modifications make it possible for teleosts to protrude their jaws outwards from the mouth. The caudal fin is homocercal, meaning the upper and lower lobes are about equal in size. The spine ends at the caudal peduncle, distinguishing this group from those in which the spine extends into the upper lobe of the caudal fin.

Striped marlin are teleosts



Rose fish are also teleosts



Eels are teleosts too

So are seahorses

By size

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

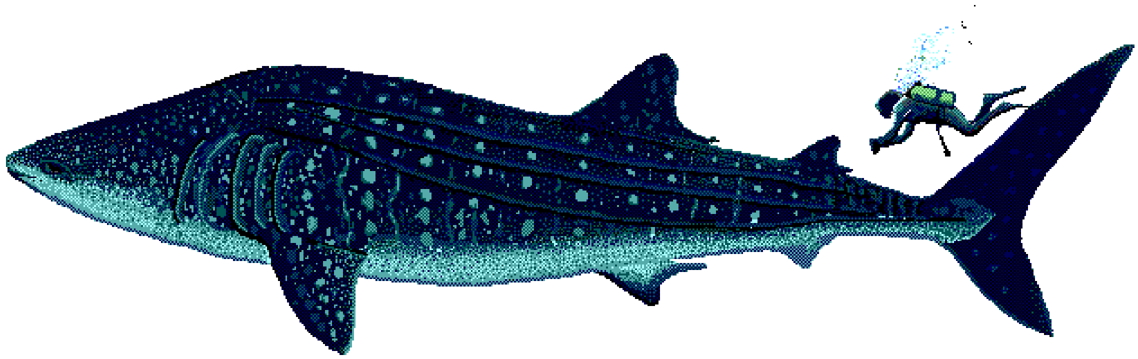
Other contenders for smallest fish are the male anglerfish, *Photocorynus spiniceps*, and the stout infantfish, a type of goby. According to the Guinness Book of World Records, the sinarapan, another type of goby, is the world's smallest commercially harvested fish.

Found in the Philippines, they have an average length of 12.5 millimeters (0.5 in), and are threatened by overfishing.

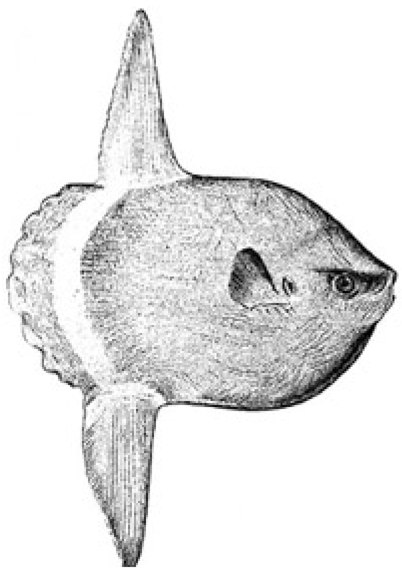
The largest is the whale shark. It is a slow moving filter feeding shark with a maximum published length of 20 meters (66 ft) and a maximum weight of 34 tonnes. Whale sharks can live up to 70 years.

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

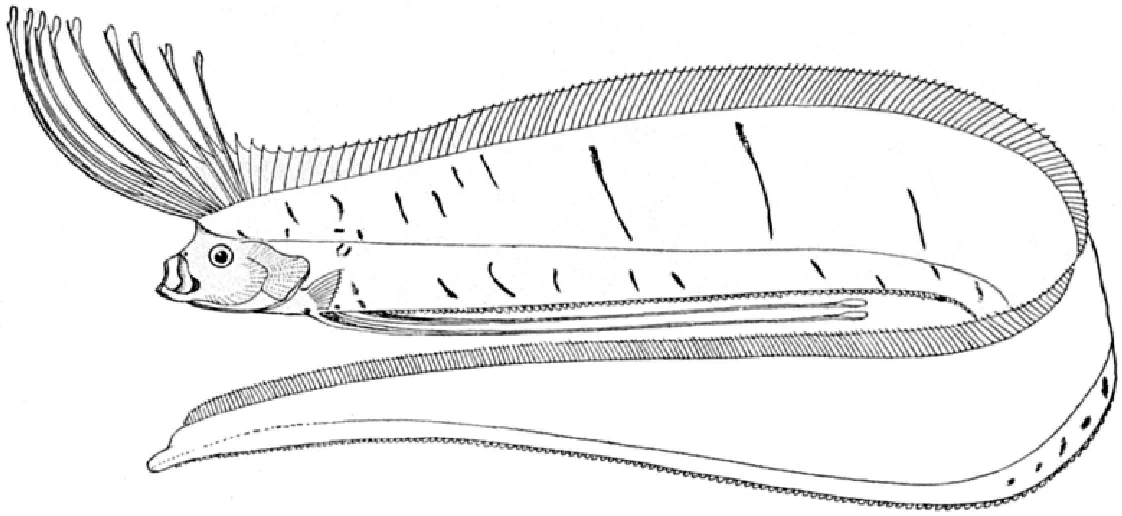
Some of the smallest fishes are minnow-type fishes, including the smallest of all, *Paedocypris progenetica*.



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



The ocean sunfish is the heaviest bony fish



The king of herrings is the longest bony fish

By life span

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

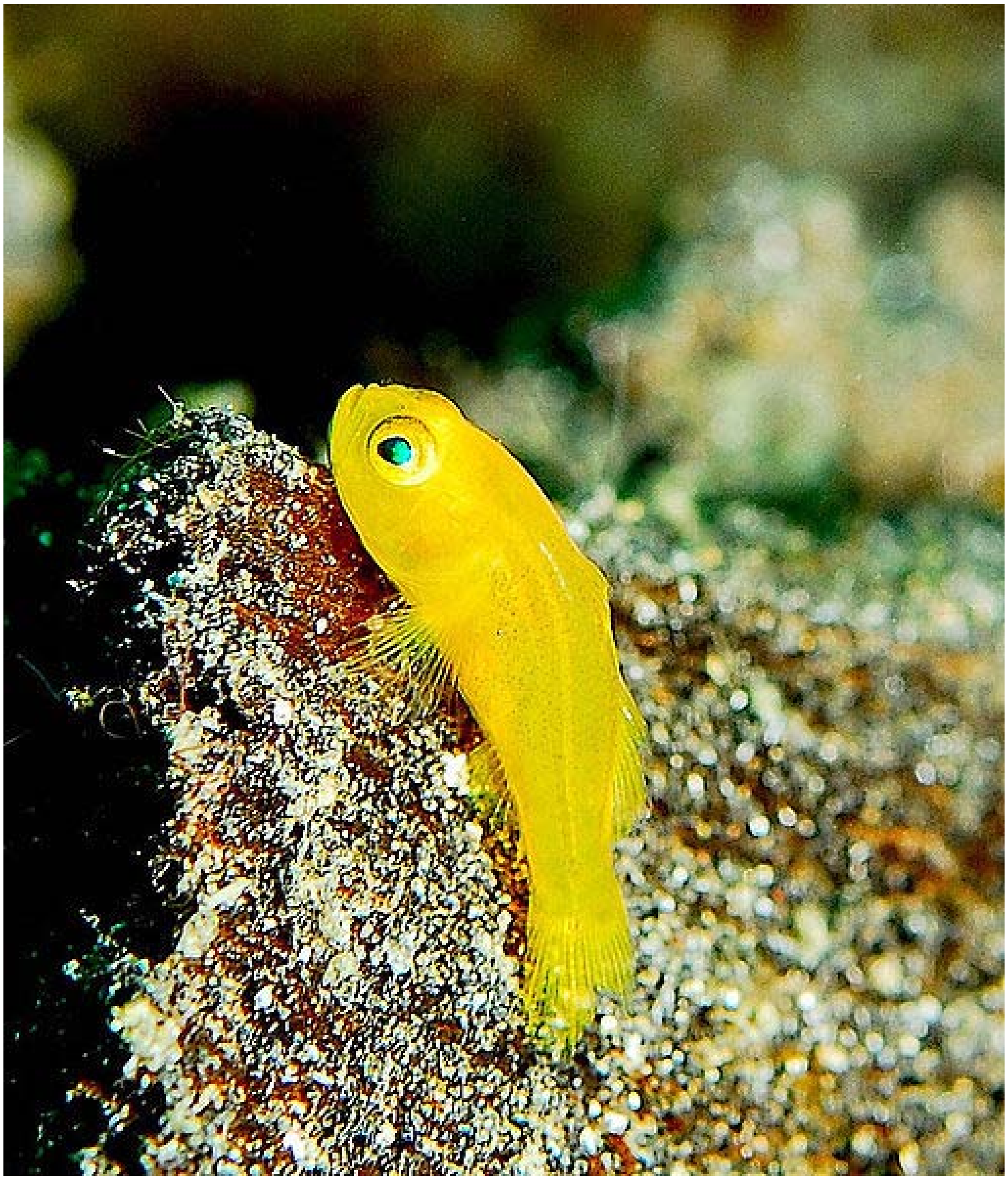
The shortest lived is the seven-figure pygmy goby, which lives for at most 59 days. This is the shortest lifespan for any vertebrate. Short lived fish have particular value in genetic studies on aging. In particular, the ram cichlid is used in laboratory studies because of its ease of breeding and predictable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

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

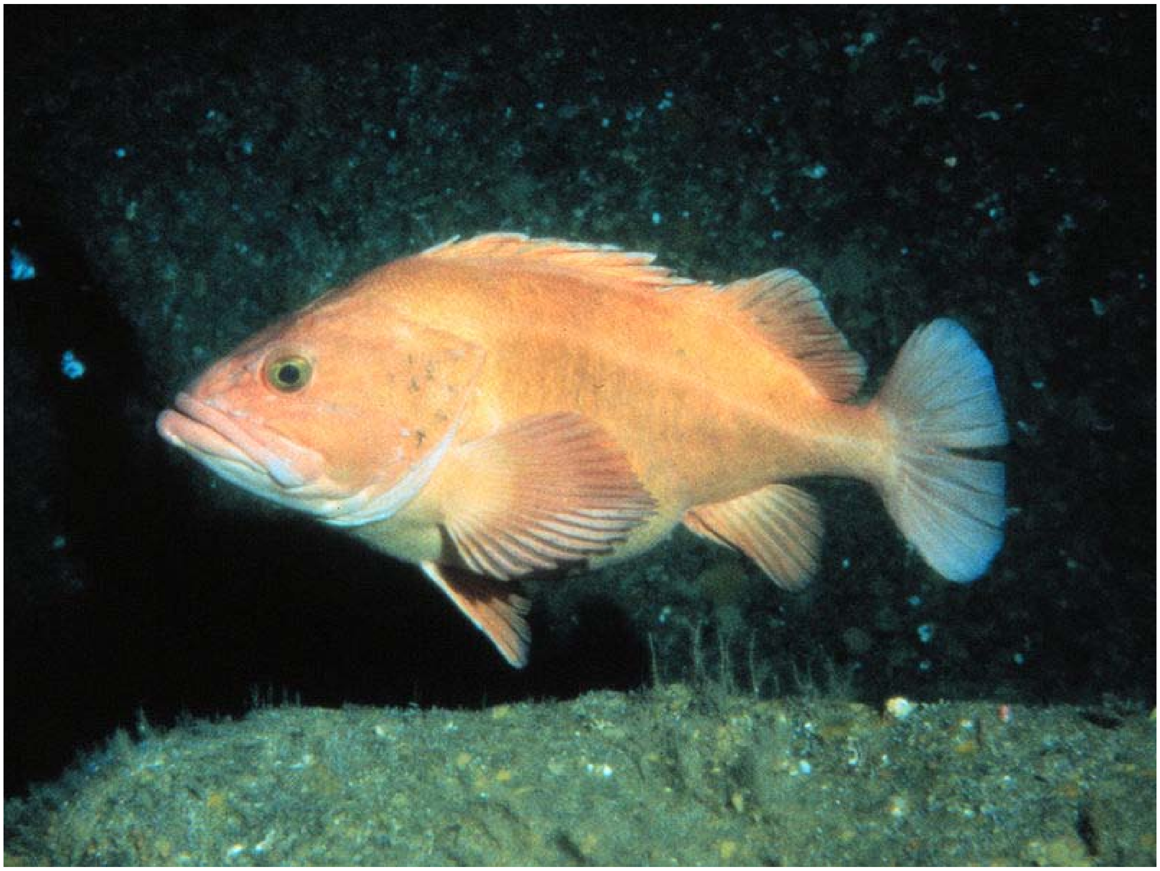
There are stories about Japanese Koi goldfish passed from generation to generation for 300 years. Scientists are sceptical. Counting growth lines on the scales of fish confined to ponds or bowls is unreliable, since they lay down extra lines. The maximum reliably reported age for a goldfish is 41 years

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

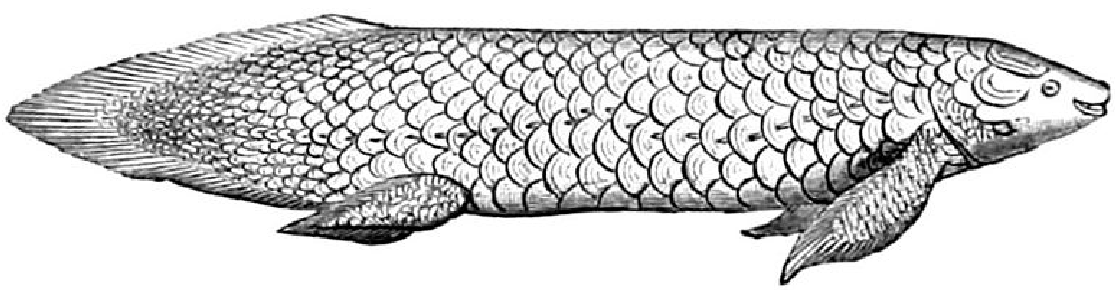
Some of the longest living fish are living fossils, such as the green sturgeon. This species is among the longest living species found in freshwater, with a maximum reported age of 60 years. They are also among the largest fish species found in freshwater, with a maximum reported length of 2.5 meters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



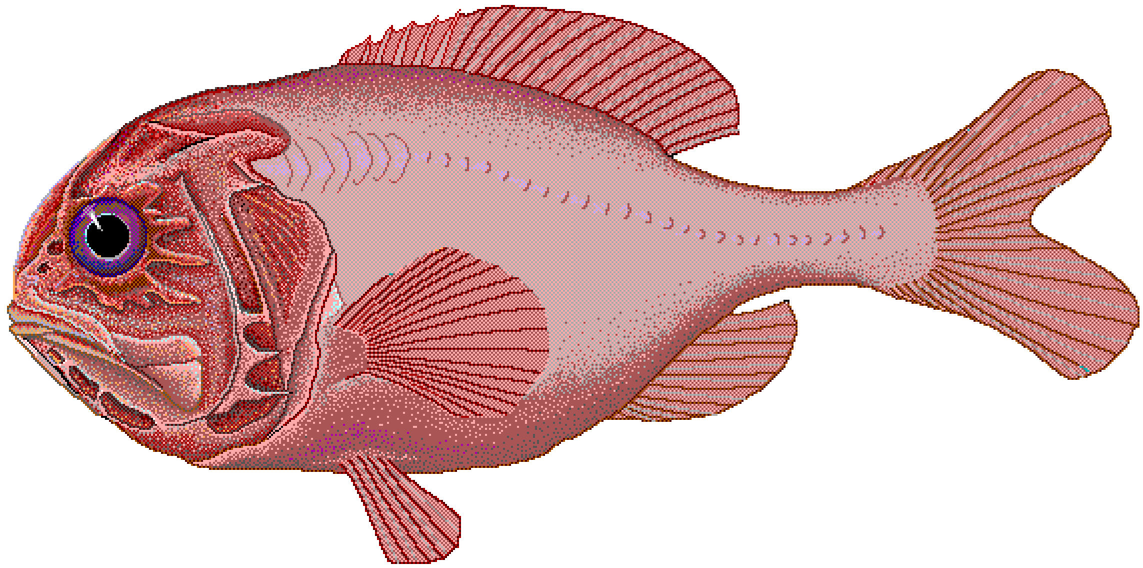
Among gobies, small coral reef-dwelling fish, are some of the shortest lived fishes with the seven-figure pygmy goby living at most for 59 days.



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



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



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

By habitat

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

Habitat	**Area**	**Volume**	**Depth**	**Species**		**Fish biomass**
	million km²	**million cu km**	**(mean)**	**count**	**percent**	**million tonnes**
Saltwater	361	1370.8	3.8 km	18,000	58	800-2,000
Freshwater	1.5	0.13	87 m	13,000	41	

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

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

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

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

The blue shark ranges across all oceans

The blind cave fish live in caves

By breeding behavior

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

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

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

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

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

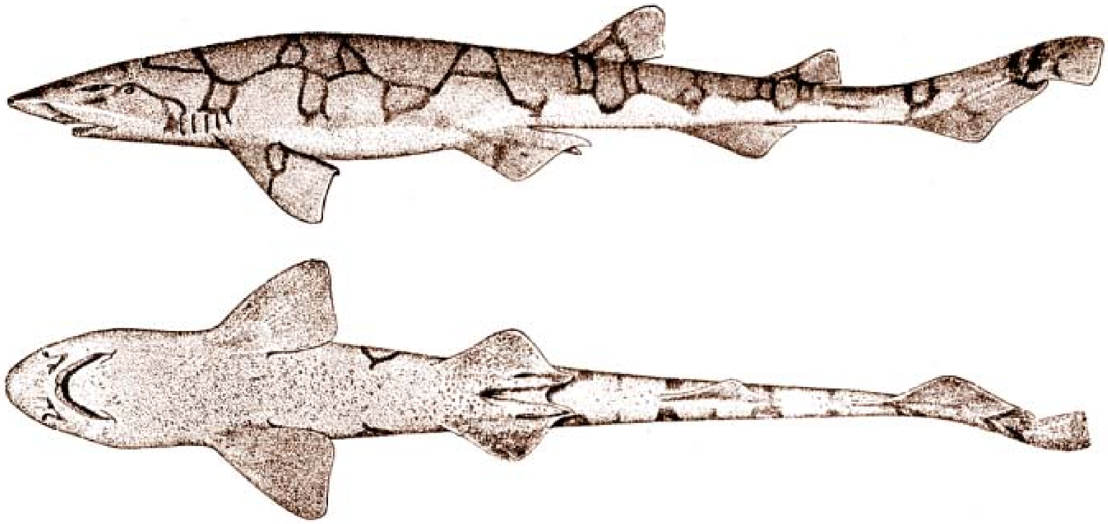
By brooding behavior

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

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

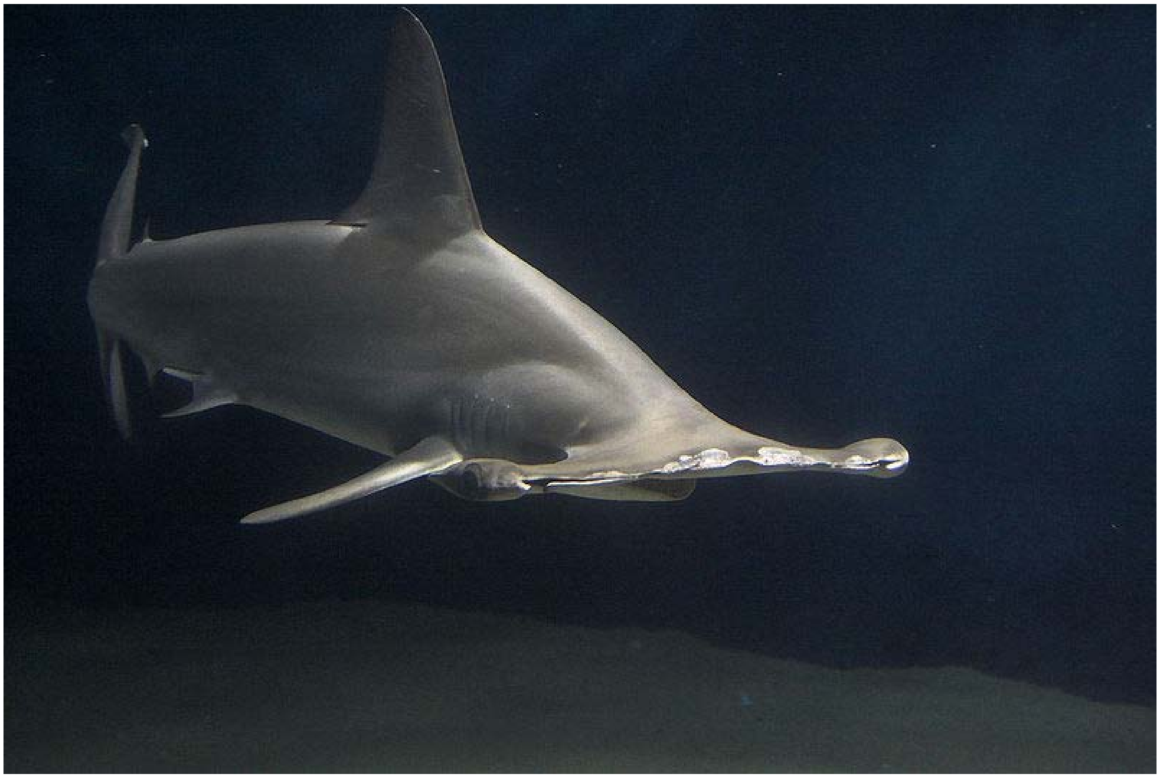
Others, such as seahorse males, practice pouch-brooding, analogous to Australia's kangaroos, nourishing their offspring in a pouch in which the female lays them.

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



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

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



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

By feeding behaviour

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

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

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

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

A pomfret with bite wounds from a cookiecutter shark.

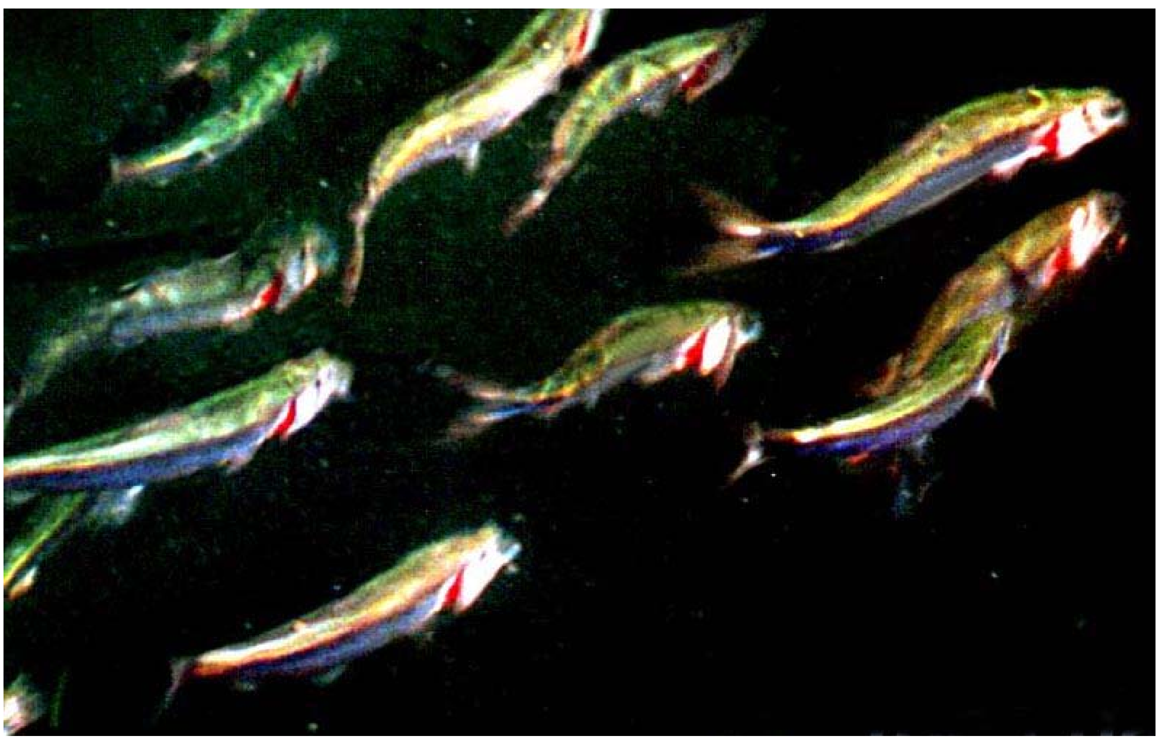
Striped bass eat smaller fish

Chinese algae eaters are kept in aquaria to control algae.

The Emperor angelfish feeds on coral sponges

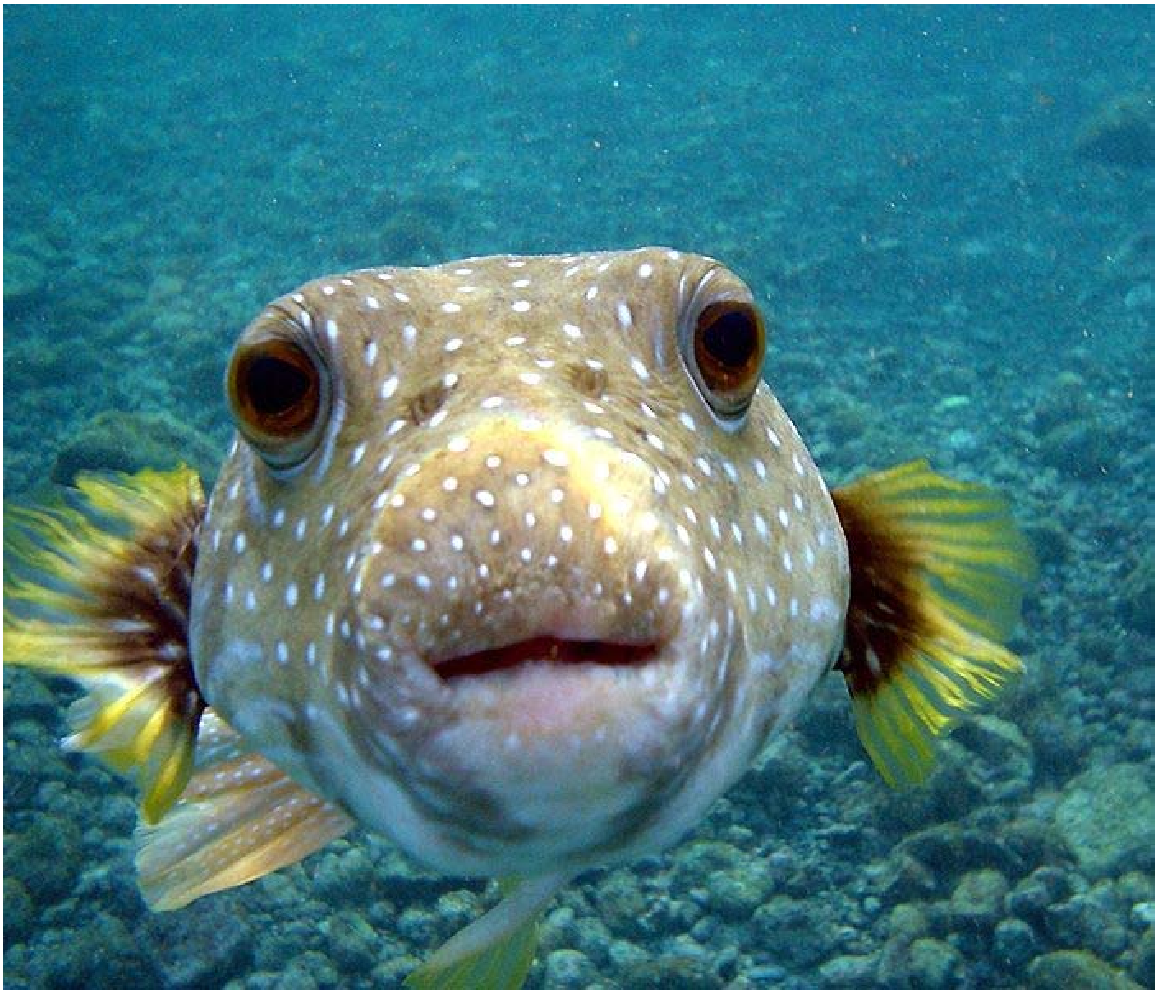
Most fish are food opportunists, or generalists. They eat whatever is most easily available. For example, the blue shark feeds on dead whales and nearly everything else that wriggles: other fish, cephalopods, gastropods, ascidians, crustaceans. Ocean sunfish prefer jellyfish.

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

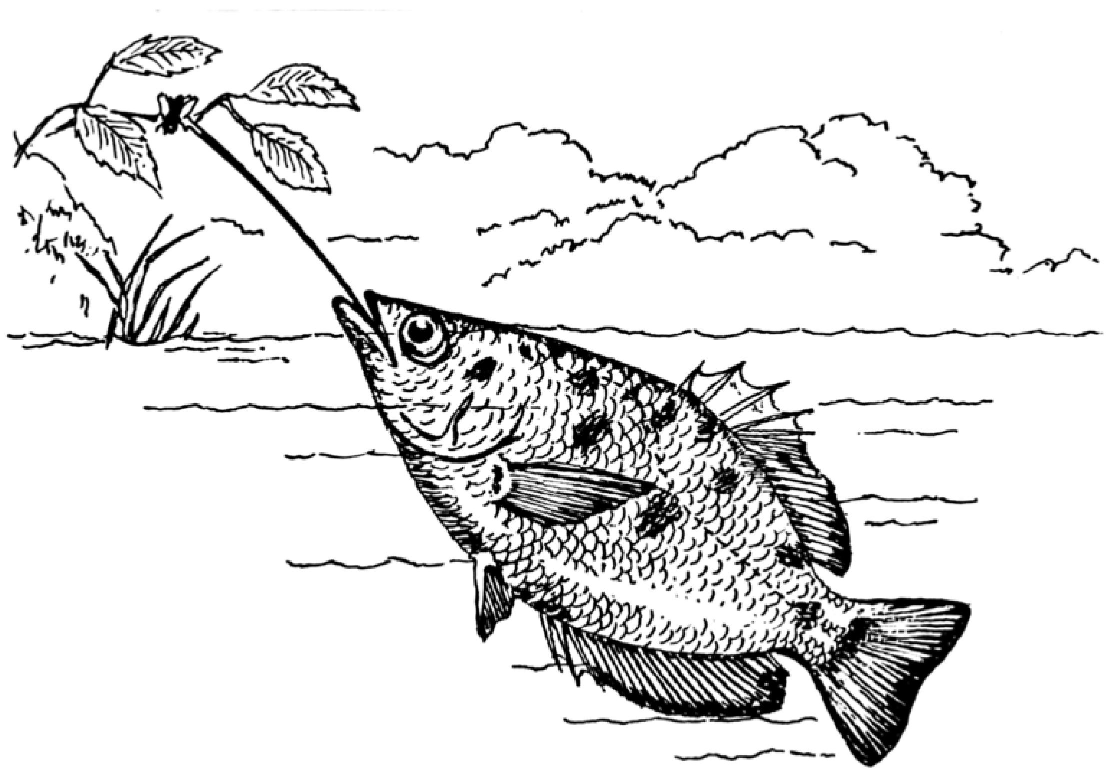


Schooling herrings ram feed on copepods

The mangrove jack eats crustaceans



Many puffer fish species crush the shells of mollusks



Archerfish shooting down an insect using a jet of water

Other fish have developed extreme specializations. Silver arowana, also called *monkey fish*, can leap two meters out of the water to capture prey. They usually swim near the surface of the water waiting for potential prey. Their main diet consist of crustaceans, insects, smaller fishes and other animals that float on the water surface, for which its draw-bridge-like mouth is exclusively adapted for feeding. The remains of small birds, bats, and snakes have also been found in their stomachs.

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

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

The bucktoothed tetra eats scales off other fishes (lepidophagy)

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

Doctor fish nibbling on the diseased skin of patients

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

By locomotion

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

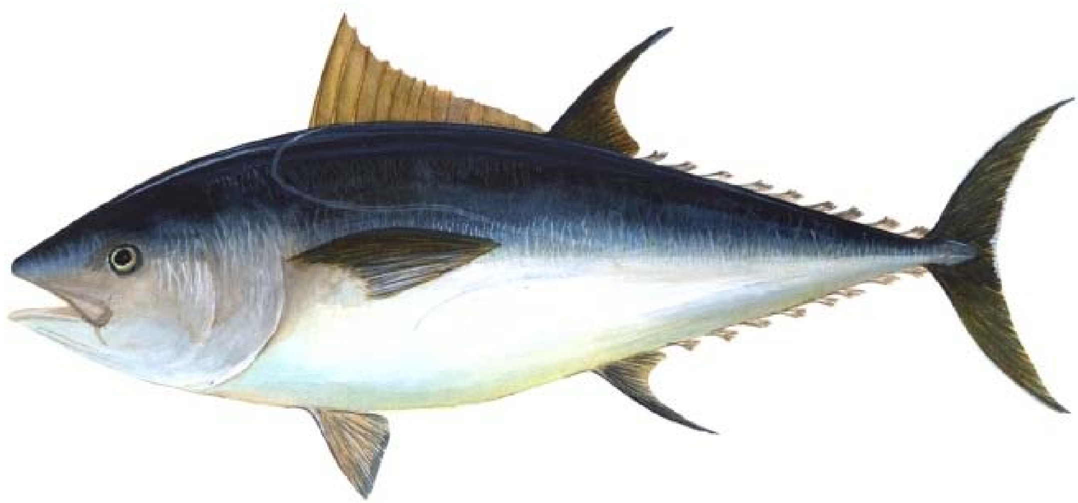
Among the fasted sprinters are the Indo-Pacific sailfish and the black marlin. Both have been recorded in a burst at over 110 kilometres per hour (68 mph). For the sailfish, that is equivalent to 12 to 15 times their own length per second. The wahoo is perhaps the fastest fish for its size, attaining a speed of 19 lengths per second, reaching 78 kilometres per hour (48 mph).

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

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

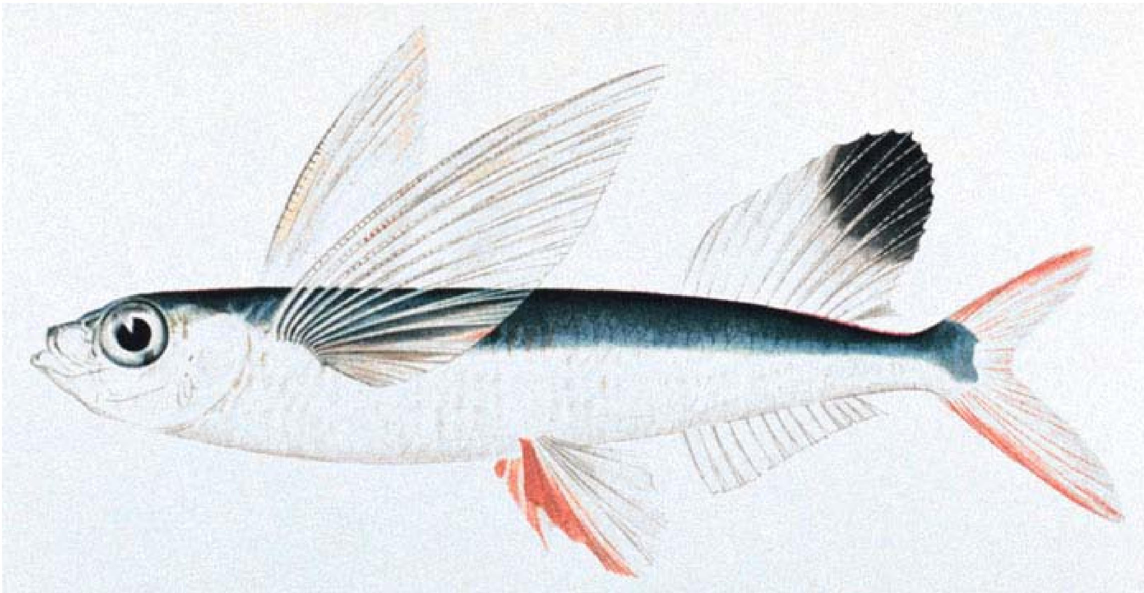
The slowest fishes are the seahorses, and the tiny dwarf seahorse is the slowest of all

One of the fasted sprinters is the Indo-Pacific sailfish



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

Flying fish taking off into a glide



Flying fish

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

The mudskipper is a type of walking fish

Walking fish are often amphibious and can travel over land for extended periods of time. Able to spend longer times out of water, these fish may use a number of means of locomotion, including springing, snake-like lateral undulation, and tripod-like walking.

The mudskipper is probably the best land-adapted of contemporary fish and is able to spend days moving about out of water and can even climb mangroves, although to only modest heights. There are some species of fish that can "walk" along the sea floor but not on land. One such animal is the flying gurnard, which can walk on the sea floor.

By toxicity

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

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

The most poisonous fish is the puffer fish. It is the second most poisonous vertebrate after the golden dart frog. It paralyzes the diaphragm muscles of human victims, who can die from suffocation. In Japan, skilled chefs use parts of a closely related species, the blowfish to create a delicacy called "fugu", including just enough toxin for that "special flavour".

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

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

The puffer fish is the most poisonous fish in the world

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

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

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

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

The most venomous known fish is the reef stonefish

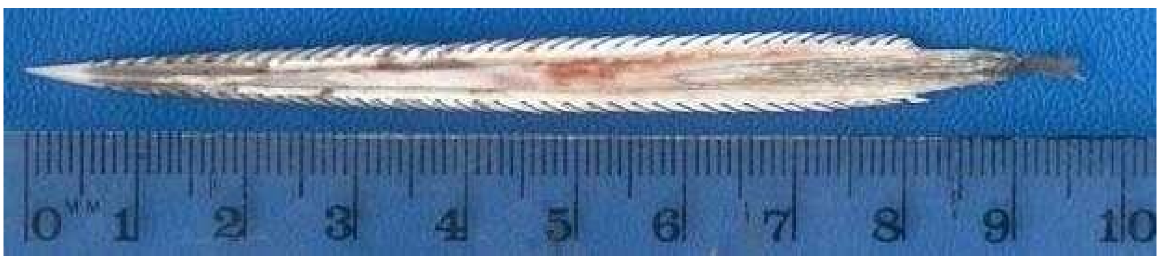
Head on view of the beautiful lionfish, a venomous coral reef fish

The stargazer *Uranoscopus sulphureus*

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

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

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



A stingray's stinger

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

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

By human use

Predator fish size up schooling forage fish

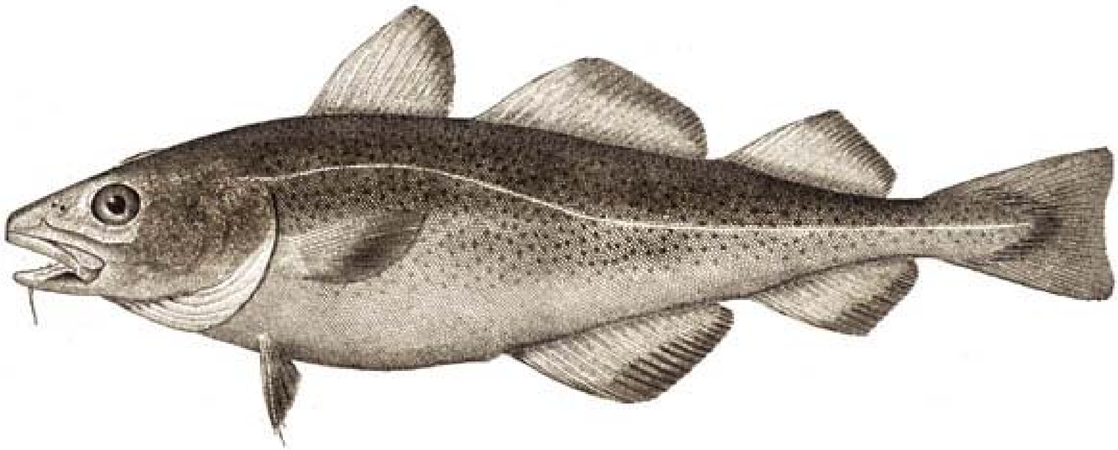
Fish are sought by humans for their value as commercial food fish, recreational sport fish, decorative aquarium fish and in tourism, attracting snorkelers and SCUBA divers.

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

Higher in the food chain, Gadidae (cod, pollock, haddock, saithe, hake and whiting also support important fisheries. Concentrated initially in the North Sea, Atlantic cod was one of Europe's oldest fisheries, later extending to the Grand Banks, Declining numbers led to international "cod wars" and eventually the virtual abandonment of these fisheries. These days the Alaska pollock supports an important fishery in the Bering Sea and the north Pacific, yielding about 6 million tonnes, while cod amounts to about 9 million tonnes.

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

These schooling anchovy are forage fish



Atlantic cod fisheries have collapsed

Alaska Pollock

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

- Food fish, Oily fish, whitefish
- Farmed fish
- fish used for medicinal purposes

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

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

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

By vulnerability

- resilience

Other types

Four-eyed fish

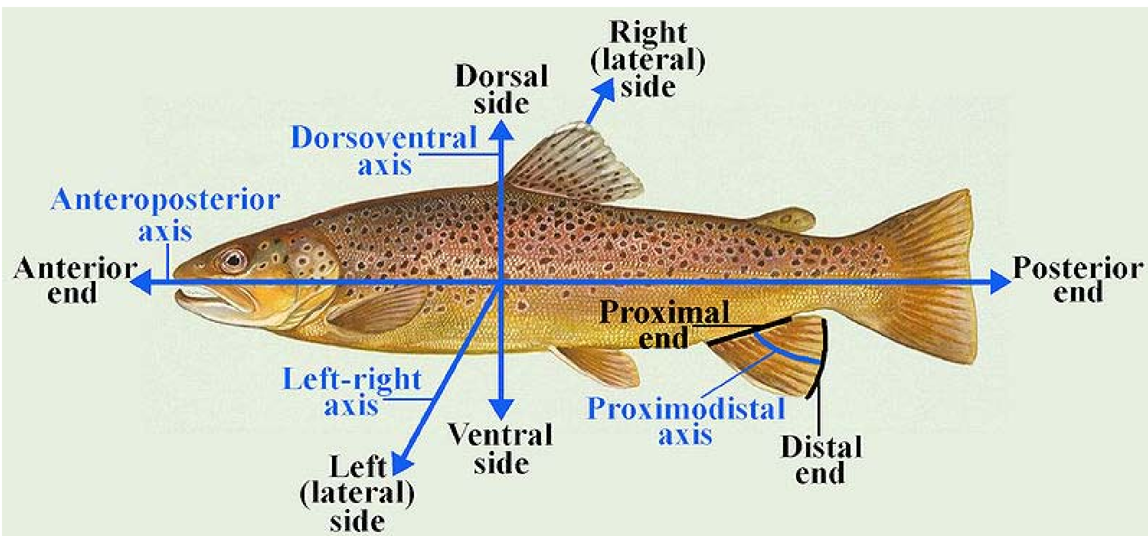
Four-eyed fish have eyes raised above the top of the head and divided in two different parts, so that they can see below and above the water surface at the same time. Four-eyed fish actually have only two eyes, but their eyes are specially adapted for their surface-dwelling lifestyle. The eyes are positioned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

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

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

Chapter- 3

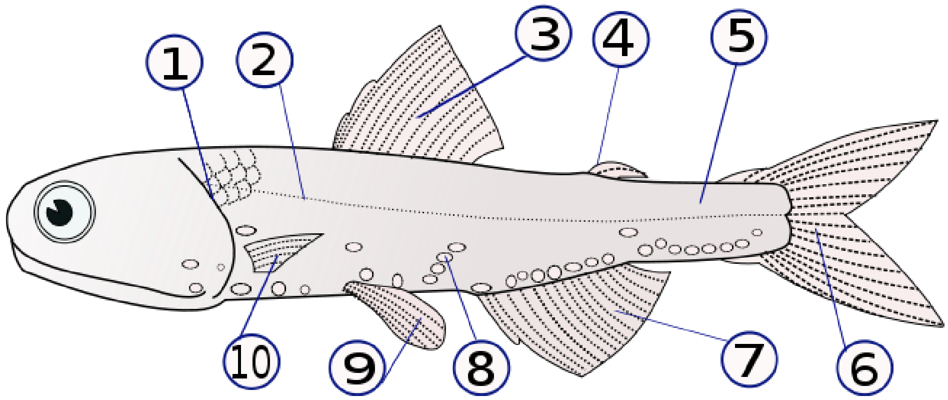
Fish Anatomy



Anatomical directions and axes

Fish anatomy is primarily governed by the physical characteristics of water, which is much denser than air, holds a relatively small amount of dissolved oxygen, and absorbs more light than air does.

Fins



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

The *fins* are the most distinctive features of a fish, composed of bony spines protruding from the body with skin covering them and joining them together, either in a webbed fashion, as seen in most bony fish, or more similar to a flipper, as seen in sharks. These usually serve as a means for the fish to swim. Fins can also be used for gliding or crawling, as seen in the flying fish and frogfish. Fins located in different places on the fish serve different purposes, such as moving forward, turning, and keeping an upright position.

Spines and rays

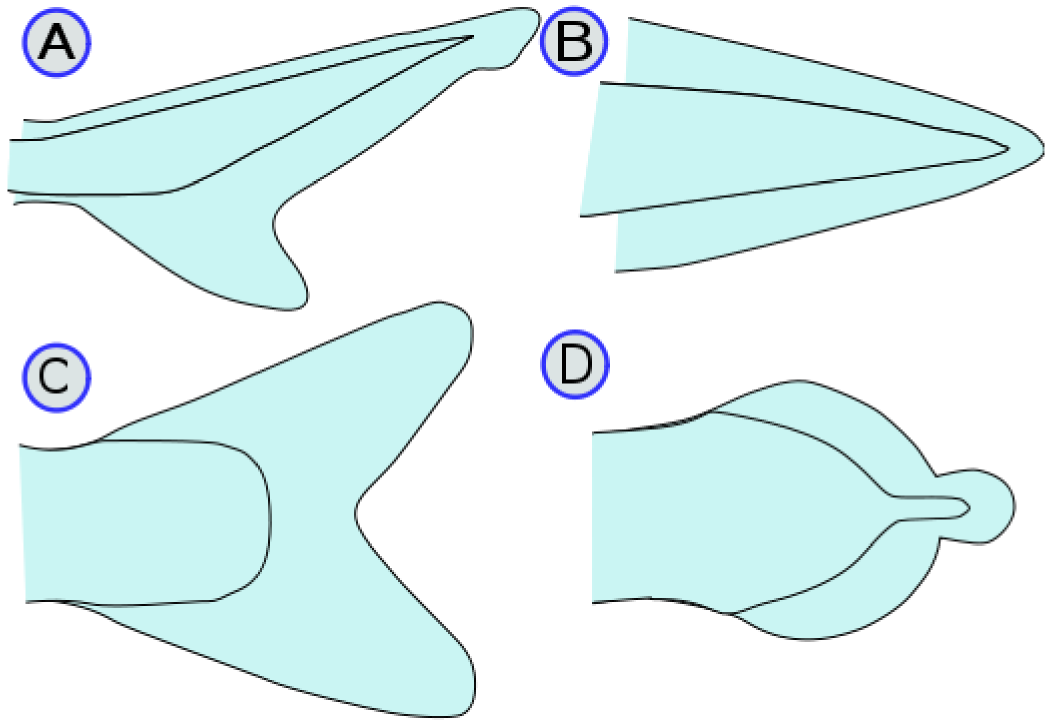
In bony fish, most fins may have **spines** or **rays**. A fin can contain only spiny rays, only soft rays, or a combination of both. If both are present, the spiny rays are always anterior. Spines are generally stiff and sharp. Rays are generally soft, flexible, segmented, and may be branched. This segmentation of rays is the main difference that separates them from spines; spines may be flexible in certain species, but they will never be segmented.

Spines have a variety of uses. In catfish, they are used as a form of defense; many catfish have the ability to lock their spines outwards. Trigger fish also use spines to lock themselves in crevices to prevent them being pulled out.

Types of fin

- **Dorsal fins** are located on the back. A fish can have up to three of them. The dorsal fins serve to protect the fish against rolling, and assists in sudden turns and stops.
    - In anglerfish, the anterior of the dorsal fin is modified into an **illicium** and **esca**, a biological equivalent to a fishing pole and a lure.
    - The bones that support the dorsal fin are called *Pterygiophore*. There are two to three of them: "proximal", "middle", and "distal". In spinous fins the distal is often fused to the middle, or not present at all.

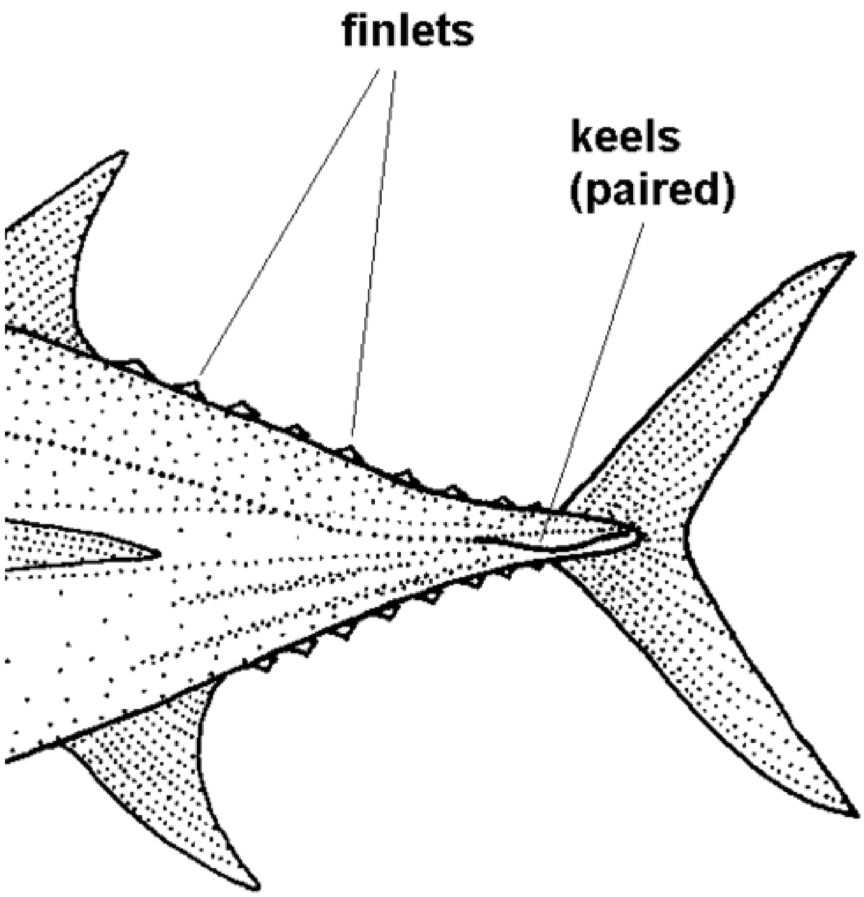
- The **caudal fin** is the tail fin, located at the end of the caudal peduncle and is used for propulsion.



types of caudal fin :
(A) - Heterocercal, (B) - Protocercal,
(C) - Homocercal, (D) - Diphycercal

  - The tail can be **heterocercal**, which means that the vertebrae extend into a larger lobe of the tail or that the tail is asymmetrical
    - **Epicercal** means that the upper lobe is longer (as in sharks)
    - **Hypocercal** means that the lower lobe is longer (as in flying fish)
  - **Protocercal** means that the caudal fin extends around the vertebral column, present in embryonic fish and hagfish. This is not to be confused with a caudal fin that has fused with the dorsal and anal fins to form a contiguous fin.
  - **Diphycercal** refers to the special, three-lobed caudal fin of the coelacanth and lungfish where the vertebrae extend all the way to the end of the tail.
  - Most fish have a **homocercal** tail, where the vertebrae do not extend into a lobe and the fin is more or less symmetrical. This can be expressed in a variety of shapes.
    - The tail fin may be **rounded** at the end.
    - The tail fin may be **truncated**, or end in a more-or-less vertical edge (such as in salmon).
    - The fin may be **forked**, or end in two prongs.
    - The tail fin may be **emarginate**, or with a slight inward curve.
    - The tail fin may be **lunate**, or shaped like a crescent moon.

- The **anal fin** is located on the ventral surface behind the anus. This fin is used to stabilize the fish while swimming.
- The paired **pectoral fins** are located on each side, usually just behind the operculum, and are homologous to the forelimbs of tetrapods.
  - A peculiar function of pectoral fins, highly developed in some fish, is the creation of the dynamic lifting force that assists some fish, such as sharks, in maintaining depth and also enables the "flight" for flying fish.



Bigeye tuna *Thunnus obesus* showing finlets and keels.
Drawing by Dr Tony Ayling

  - In many fish, the pectoral fins aid in walking, especially in the lobe-like fins of some anglerfish and in the mudskipper.
  - Certain rays of the pectoral fins may be adapted into finger-like projections, such as in sea robins and flying gurnards.

        - The "horns" of manta rays and their relatives are called **cephalic fins**; this is actually a modification of the anterior portion of the pectoral fin.
- The paired **pelvic** or **ventral fins** are located ventrally below the pectoral fins. They are homologous to the hindlimbs of tetrapods. The pelvic fin assists the fish in going up or down through the water, turning sharply, and stopping quickly.
    - In gobies, the pelvic fins are often fused into a single sucker disk. This can be used to attach to objects.

The adipose fin of a trout

- The **adipose fin** is a soft, fleshy fin found on the back behind the dorsal fin and just forward of the caudal fin. It is absent in many fish families, but is found in Salmonidae, characins and catfishes. It's function is unknown, and it is frequently clipped off to mark hatchery-raised fish, though recent data shows that trout with their adipose fin removed have an 8% higher tailbeat frequency.
- Some types of fast-swimming fish have a horizontal **caudal keel** just forward of the tail fin. This is a lateral ridge on the caudal peduncle, usually composed of scutes (see below), that provides stability and support to the caudal fin. There may be a single paired keel, one on each side, or two pairs above and below.
- **Finlets** are small fins, generally behind the dorsal and anal fins (in bichirs, there are only finlets on the dorsal surface and no dorsal fin). In some fish such as tuna or sauries, they are rayless, non-retractable, and found between the last dorsal and/or anal fin and the caudal fin.

For every fin, there are a number of fish species in which this particular fin has been lost during evolution.

Reproductive system

Internal fertilization

In many species of fish, fins have been modified to allow internal fertilization. A **gonopodium** is an anal fin that is modified into an intromittent organ in males of certain species of live-bearing fish in the families Anablepidae and Poeciliidae. It is movable and used to impregnate females during mating. The male's anal fin's 3rd, 4th and 5th rays are formed into a tube like structure in which the sperm of the fish is ejected. In some species, the gonopodium may be as much as 50% of the total body length. Occasionally the fin is too long to be used, as in the "lyretail" breeds of *Xiphophorus helleri*. Hormone treated females may develop gonopodia. These are useless for breeding. One finds similar organs having the same characteristics in other types of fish, for example the **andropodium** in the *Hemirhamphodon* or in the Goodeidae.

When ready for mating, the gonopodium becomes "erect" and points forward, towards the female. The male shortly inserts the organ into the sex opening of the female, with hook-like adaptations that allow the fish to grip onto the female to insure impregnation. If a female remains stationary and her partner contacts her vent with his gonopodium, she is fertilized. The sperm is preserved in the female's oviduct. This allows females to, at any time, fertilize themselves without further assistance of males.

Male cartilaginous fish have **claspers** modified from pelvic fins. These are intromittent organs, used to channel semen into the female's cloaca during copulation.

Skin

The outer body of many fish is covered with **scales**. Some species are covered instead by **scutes**. Others have no outer covering on the skin; these are called **naked** fish. Most fish are covered in a protective layer of slime (mucus).

There are four types of fish scales.

1. **Placoid scales**, also called **dermal denticles**, are similar to teeth in that they are made of dentin covered by enamel. They are typical of sharks and rays.
2. **Ganoid scales** are flat, basal-looking scales that cover a fish body with little overlapping. They are typical of gar and bichirs.
3. **Cycloid scales** are small oval-shaped scales with growth rings. Bowfin and remora have cycloid scales.
4. **Ctenoid scales** are similar to the cycloid scales, with growth rings. They are distinguished by spines that cover one edge. Halibut have this type of scale.

Another, less common, type of scale is the **scute**, which is:

- an external shield-like bony plate, or
- a modified, thickened scale that often is keeled or spiny, or
- a projecting, modified (rough and strongly ridged) scale, usually associated with the lateral line, or on the caudal peduncle forming caudal keels, or along the ventral profile. Some fish, such as pineconefish, are completely or partially covered in scutes.

Vertebrae

The vertebrae of lobe-finned fishes consist of three discrete bony elements. The vertebral arch surrounds the spinal cord, and is of broadly similar form to that found in most other vertebrates. Just beneath the arch lies a small plate-like **pleurocentrum**, which protects the upper surface of the notochord, and below that, a larger arch-shaped **intercentrum** to protect the lower border. Both of these structures are embedded within a single cylindrical mass of cartilage. A similar arrangement was found in primitive tetrapods, but, in the evolutionary line that led to reptiles (and hence, also to mammals and birds), the intercentrum became partially or wholly replaced by an enlarged pleurocentrum, which in turn became the bony vertebral body.

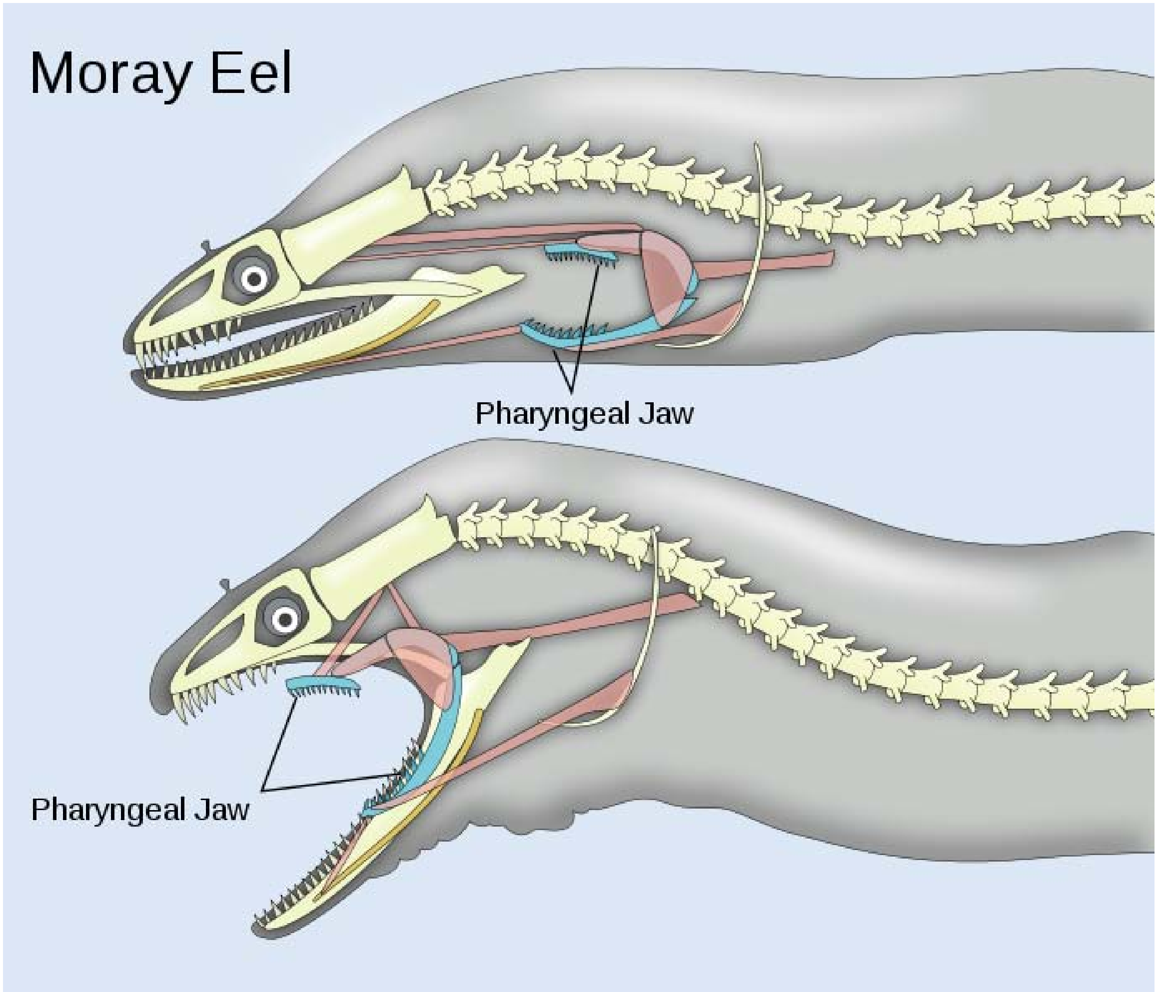
In most ray-finned fishes, including all teleosts, these two structures are fused with, and embedded within, a solid piece of bone superficially resembling the vertebral body of mammals. In living amphibians, there is simply a cylindrical piece of bone below the vertebral arch, with no trace of the separate elements present in the early tetrapods.

In cartilagenous fish, such as sharks, the vertebrae consist of two cartilagenous tubes. The upper tube is formed from the vertebral arches, but also includes additional cartilagenous structures filling in the gaps between the vertebrae, and so enclosing the spinal cord in an essentially continuous sheath. The lower tube surrounds the notochord, and has a complex structure, often including multiple layers of calcification.

Lampreys have vertebral arches, but nothing resembling the vertebral bodies found in all higher vertebrates. Even the arches are discontinuous, consisting of separate pieces of arch-shaped cartilage around the spinal cord in most parts of the body, changing to long strips of cartilage above and below in the tail region. Hagfishes lack a true vertebral column, and are therefore not properly considered vertebrates, but a few tiny neural arches are present in the tail.

The jaw

Jaws of great white shark



Moray eels have two sets of jaws: the oral jaws that capture prey and the pharyngeal jaws that advance into the mouth and move prey from the oral jaws to the esophagus for swallowing

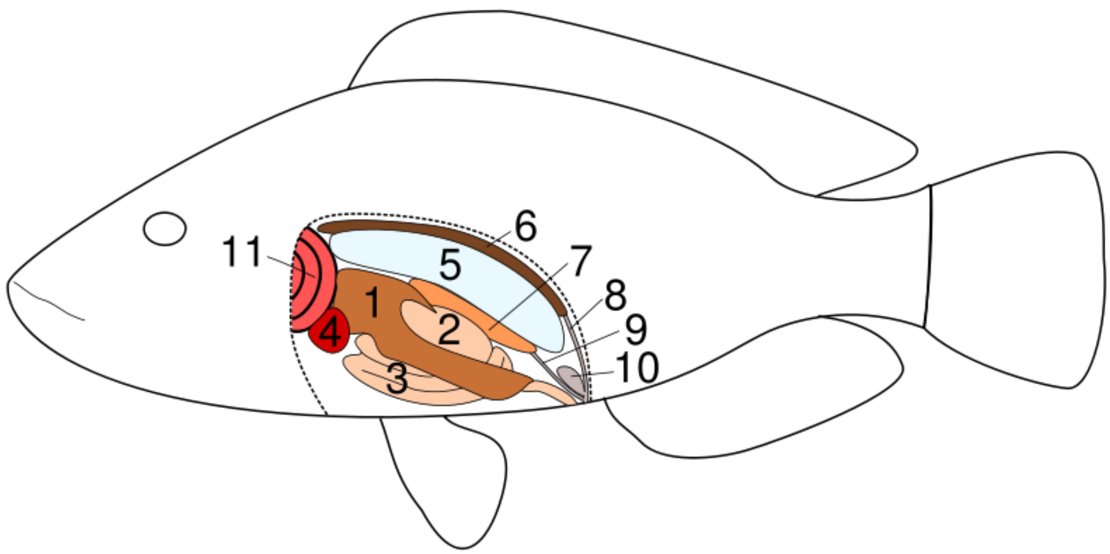
Linkage systems are widely distributed in animals. The most thorough overview of the different types of linkages in animals has been provided by M. Muller, who also designed a new classification system, which is especially well suited for biological systems.

Linkage mechanisms are especially frequent and manifold in the head of bony fishes, such as wrasses, which have evolved many specialized feeding mechanisms. Especially advanced are the linkage mechanisms of jaw protrusion. For suction feeding a system of linked four-bar linkages is responsible for the coordinated opening of the mouth and 3-D expansion of the buccal cavity. Other linkages are responsible for protrusion of the premaxilla.

The vertebrate jaw probably originally evolved in the Silurian period and appeared in the Placoderm fish which further diversified in the Devonian. Jaws are thought to derive from the pharyngeal arches that support the gills in fish. The two most anterior of these arches are thought to have become the jaw itself and the hyoid arch, which braces the jaw against the braincase and increases mechanical efficiency. While there is no fossil evidence directly to support this theory, it makes sense in light of the numbers of pharyngeal arches that are visible in extant jawed (the Gnathostomes), which have seven arches, and primitive jawless vertebrates (the Agnatha), which have nine.

It is thought that the original selective advantage garnered by the jaw was not related to feeding, but to increased respiration efficiency. The jaws were used in the buccal pump (observable in modern fish and amphibians) that pumps water across the gills of fish or air into the lungs in the case of amphibians. Over evolutionary time the more familiar use of jaws (to humans), in feeding, was selected for and became a very important function in vertebrates.

Internal organs

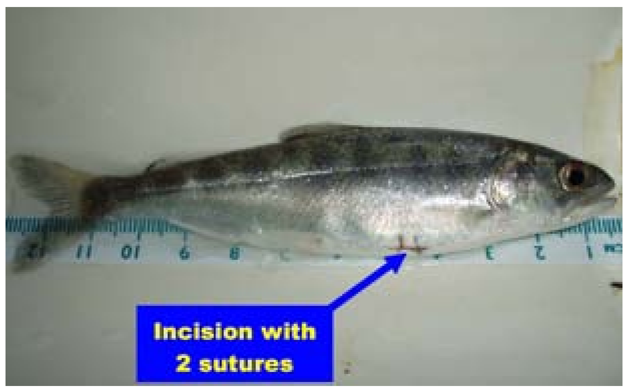


- The **gas bladder**, or swim bladder, is an internal organ that contributes to the ability of a fish to control its buoyancy, and thus to stay at the current water depth, ascend, or descend without having to waste energy in swimming. It is often absent in fast swimming fishes such as the tuna and mackerel families.
- Certain groups of fish have modifications to allow them to hear, such as the Weberian apparatus of Ostariophysians.
- The **gills**, located under the operculum, are a respiratory organ for the extraction of oxygen from water and for the excretion of carbon dioxide. They are not usually visible, but can be seen in some species, such as the frilled shark.
- The **labyrinth organ** of Anabantoidei and Clariidae is used to allow the fish to extract oxygen from the air.
- **Gill rakers** are bony or cartilaginous, finger-like projections off the gill arch which function in filter-feeders in retaining food organisms.
- Electric fish are able to produce electric fields by modified muscles in their body.

- Many fish species are hermaphrodites. *Synchronous hermaphrodites* possess both ovaries and testes at the same time. *Sequential hermaphrodites* have both types of tissue in their gonads, with one type being predominant while the fish belongs to the corresponding gender.
- The blood circulation of fishes is called "single circuit circulatory system."

Chapter- 4

Acoustic Tag



Example of post surgical implantation of tag

An **acoustic tag** is a small sound-emitting device that allows the detection and/or remote tracking of fish in three dimensions. Acoustic tags are commonly used to monitor the behavior of fish. Studies can be conducted in lakes, rivers, tributaries, estuaries or at sea. Acoustic tag tracking technology allows researchers to view 3D fish tracks in real-time with sub-meter resolution. Acoustic tags have been employed to help public utility agencies, private firms, and state and federal agencies meet fisheries regulations as defined by the Federal Regulations and Oversight of Energy known as FERC.

Acoustic tags come in an assortment of sizes and weights. To-date, the smallest acoustic tag successfully employed to provide fish behavior data in three dimensions was approximately 0.65 grams (tracking a juvenile salmonid at a length of 125 mm). Tag size increases significantly when tracking larger fish for longer periods of time (i.e. sturgeon).

Overview

Examples of acoustic tag sizes

Acoustic tags allow researchers to:

- Conduct Fish Survival Studies
- Monitor Fish Migration/Passage/Trajectory
- Track Fish Behavior in Two or Three Dimensions (2D or 3D)
- Measure Bypass Effectiveness at Dams and other Passages
- Observe Predator/Prey Dynamics and More

Acoustic Tags transmit a sound signal or "ping" that sends location information about the tagged fish to the hydrophone receiver. By tying the received acoustic signature to the known type of programmed signal code, a specific fish is identified. The transmitted signal can propagate up to 1 km (in freshwater). Each "ping" comes at a predetermined interval. The signals are encoded for strength to improve range and resolution. Thus, an array of receivers allows the user to record the movement of a particular fish over many kilometers. Unique to Acoustic Tags is the capability to have over 100,000 user-specified individual tag ID codes with battery lives up to four years. These variables allows a custom fit for unique projects.

By determining the sound's time of arrival at each hydrophone, the 3D position of the fish can be calculated. The hydrophone receiver picks up the sound signal and converts it to data that researchers use to plot the resulting tag positions in three dimensions, in real-time. Using a post processing software, such as *MarkTags*, takes that data and delivers the end result, the 3D track.

Acoustic tags can be attached to, gastrically inserted in or surgically implanted into fish (or almost any aquatic life).

Several different types of methods are used to attach the tag to the fish. The tag may be embedded in the fish by cutting a small incision in the abdominal cavity of the fish (surgical implantation), or put down the gullet to embed the Acoustic Tag in the stomach (gastric implantation). External attachment using adhesive compounds is typically not used for fish as scale fluids do not allow for any successful attachment to scale tissue.

Details

Acoustic Tags are produced in many different shapes and sizes depending on the type of species being studied, or the type of environment in which the study is conducted. Sound parameters such as frequency and modulation method are chosen for optimal detectability, and signal level. For oceanic environments, frequencies less than 100 kHz range are often used, while frequencies of several hundreds of kilohertz are more common in for studies in rivers and lakes.

A typical Acoustic Tag consists of a piezoceramic transducer, drive/timing electronics, and a battery power source. Cylindrical or “tube” transducers are often used, which have metalization on the inner and outer walls of the structure. In normal operation, an alternating current (AC) electrical signal generated by the drive/timing electronics is impressed across the two metalization layers. This voltage creates stress in the material, which in turn cause the transducer to emit an acoustic signal or “ping”, which emanates outward from the surface of the tube. An acoustic “ping” can be detected by specialized receivers, and processed using advanced signal processing techniques to determine if a fish swimming into the reception area carries a specific acoustic tag.

Acoustic Tags are distinguished from other types of devices such as radio tags, or passive inductive transponder (PIT) tags, in that they can work in either salt or freshwater (RF and PIT tags perform poorly in saltwater) and do not depend on steering the fish in a particular path (PIT tags require the fish to be routed through a restricted sensing area).

Applications

At present, acoustic tags are most commonly used to monitor fish approaching diversion and guidance structures at hydropower dams. This allows hydropowered dam facilities, public utility districts, and municipalities to evaluate specific migration pathways used by the fish (most often salmon smolts), identify where fish mortality occurs and assess fish behavior in relation to hydrodynamic conditions and/or any other environmental parameters. Ultimately, working to improve bypass effectiveness and protect fish populations, Acoustic Tag Tracking Systems are a significant breakthrough in the preservation of migrating salmon populations.

Chapter- 5

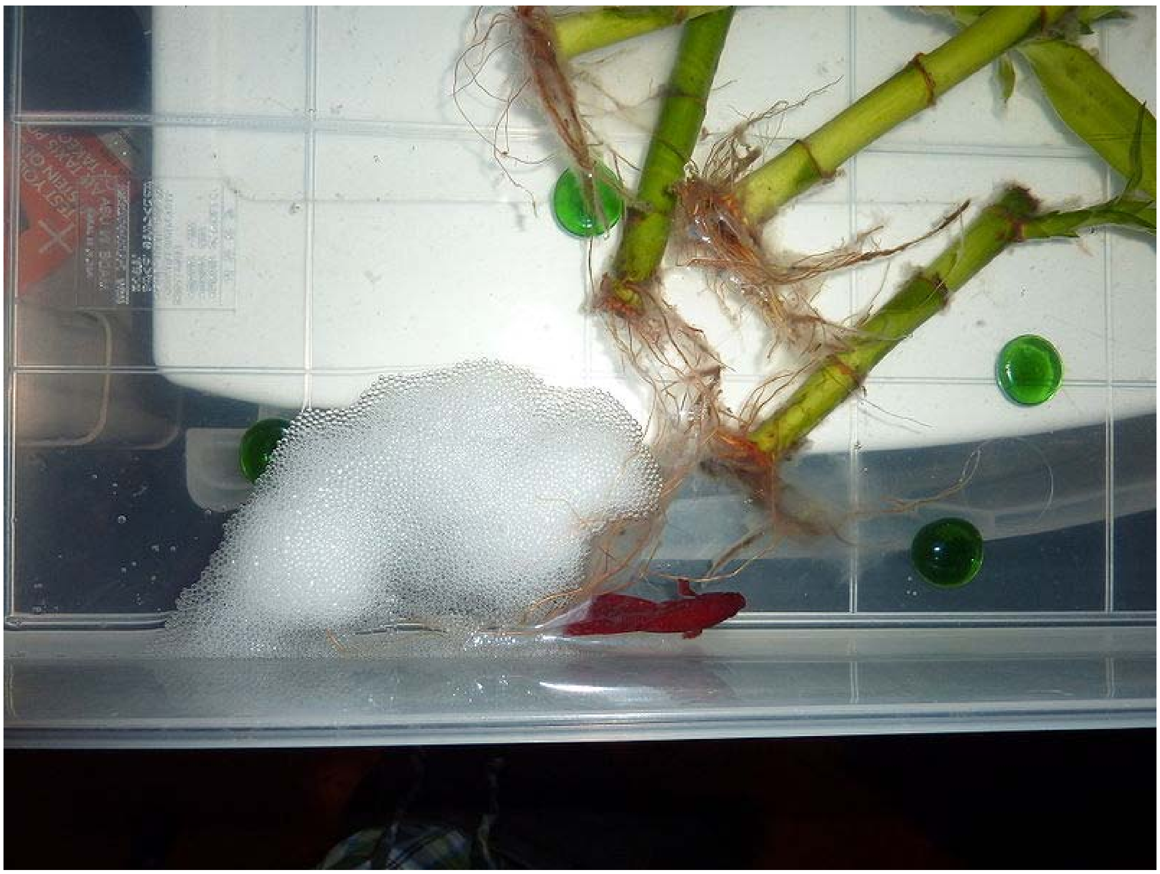
Bubble Nest & Eel Ladder

Bubble nest

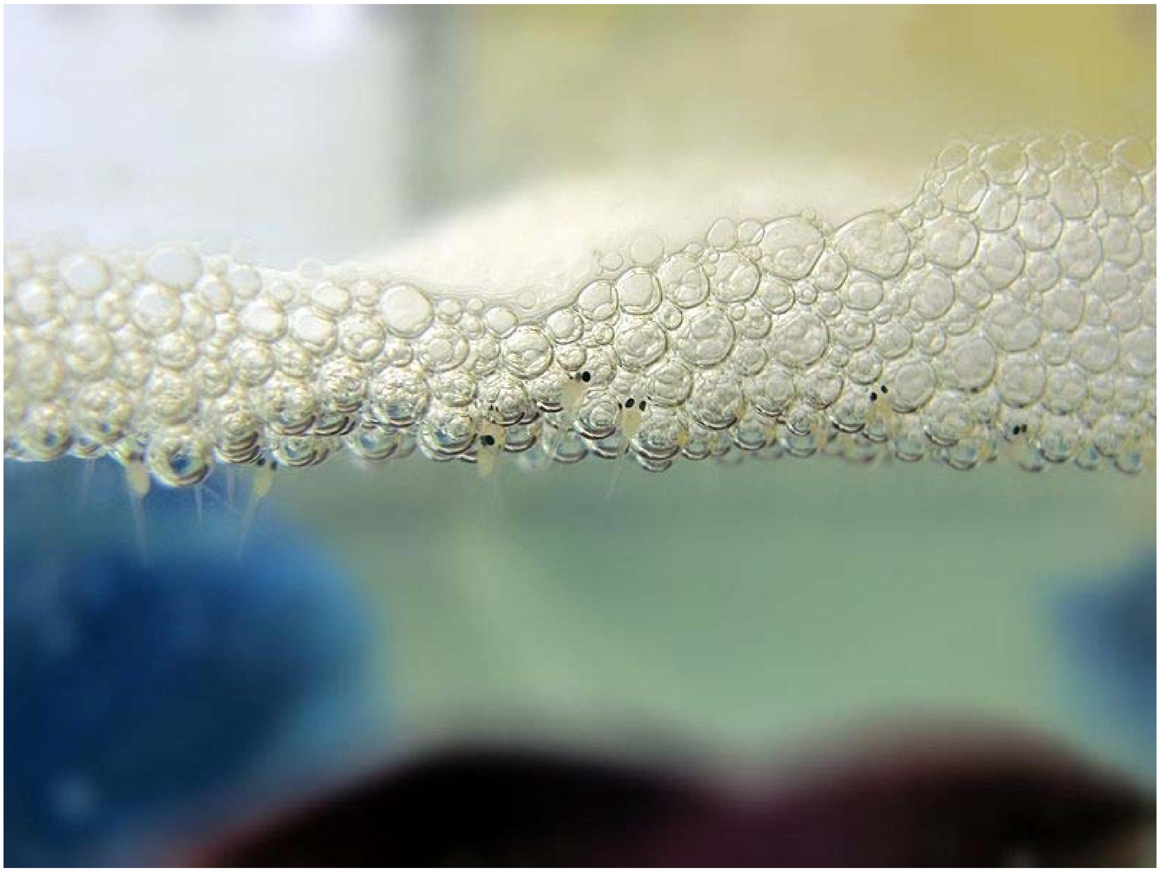
Dwarf Gourami bubble nest made of bubbles, floating plants and plant parts which were torn out from a Hydrocotyle by the gourami male.

Bubblenests, also spelled **bubble nests** or **bubble-nests**, created by some fish species, are floating masses of bubbles blown with an oral secretion, saliva bubbles, and occasionally aquatic plants, or an area for egg deposit attached at the bottom. Fish that build and guard bubble nests are known as **aphrophils**. Aphrophils include Gouramis (including *Betta* species) and the synbranchid eel *Monopterus alba* in Asia, *Ctenopoma* (Anabantidae), *Polycentropsis* (Nandidae), and *Hepsetus odoe* (the only member of Hepsetidae) in Africa, and callichthyines and the electric eel in South America. Most, if not all, fish that construct floating bubble nests live in tropical, oxygen-depleted standing waters. Also, some sunfish and cichlids create bubblenests. Anabantidae are the most commonly recognized family of bubblenest makers. The nests are constructed as a place for fertilized eggs to be deposited while incubating and guarded by the male until the fry hatch.

Construction



Betta Splendens fish build nests of varying sizes



Betta splendens fry in a bubble nest

Bubble nests are built even when not in presence of female or fry (though often a female swimming past will trigger the frantic construction of the nest). Males will build bubble nests of various sizes and thicknesses, depending on the male's territory and personality. Some males build constantly, some occasionally, some when introduced to a female and some do not even begin until after spawning. Some nests will be large, some small, some thick.

Various things have been shown to stimulate bubble nest construction, such as quick temperature changes, barometric changes, fluctuations in rainfall, materials in the tank, and presence of other males or females.

The nests are built by the male (sometimes females) and their size, position and shape depends on the species. The nest is most often made at the water surface, sometimes among floating plants, whether natural or artificial. Occasionally, every object floating will have bubbles on it.

Bubble nests created by male betta/Siamese Fighting Fish (Betta splendens) are made from air bubbles coated with saliva to increase durability. This makes a louder noise than regular breathing and is often frantic behavior.

Bubblenests and breeding

All species of bubble nesters continue parental care after construction of the floating bubble nest and spawning. After spawning, the eggs float up into the bubble nest, or are carried there held in the mouth by the male, as if he is eating them. The male lodges them in the nest to protect them, and then protects the brood by chasing away the female and any other intruders, concentrating on the eggs in the nest, retrieving any eggs or fry that fall from the nest and keeping the nest in repair. The male will guard the eggs constantly until the fry hatch in 24–48 hours and be suspended from the nest. For the next few weeks, they will stay nearby being tended by the male.

Eel ladder

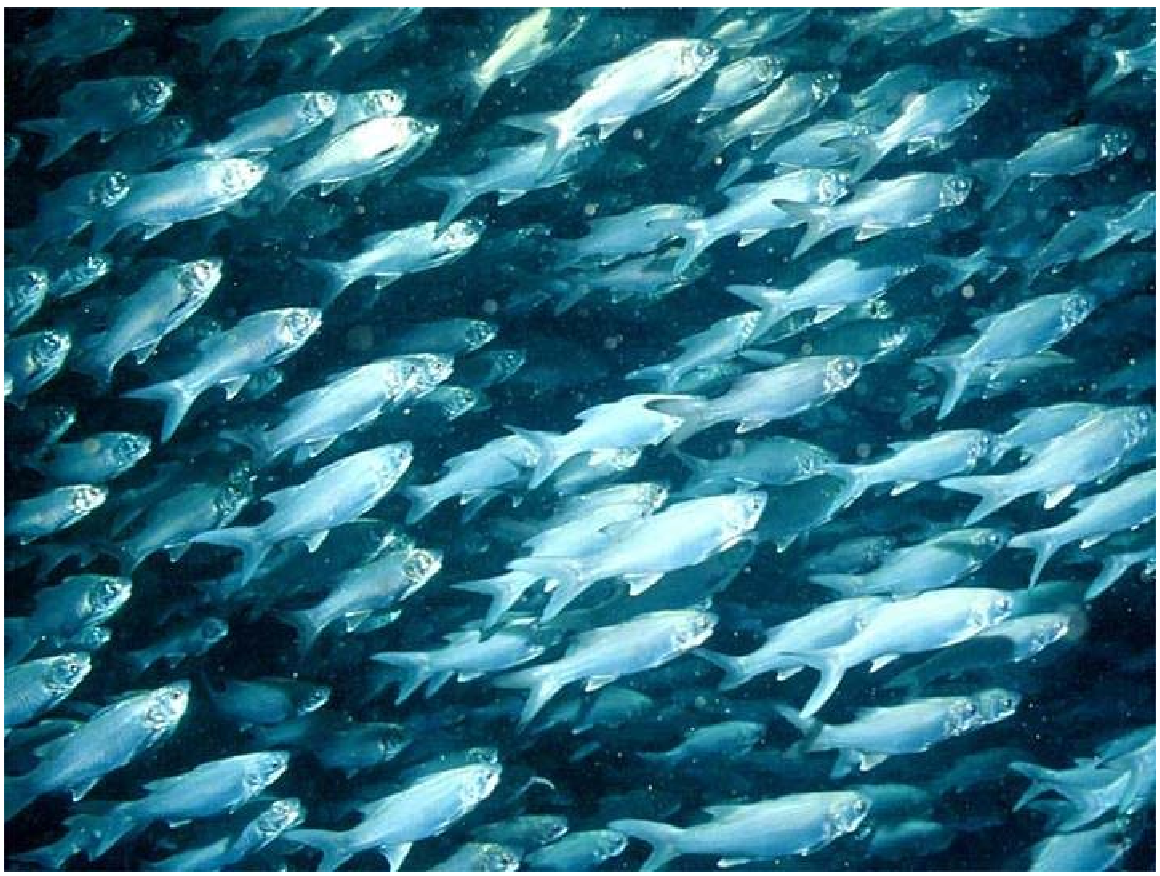
An **eel ladder** is type of fish ladder designed to help eels swim past barriers, such as dams and weirs or even natural barriers, to reach upriver feeding grounds. (Many eels are catadromous, living in fresh water but spawning at sea.) The basic design of an eel ladder has the eel swim over the barrier using an eel ascending ramp, which provides the eels a climbing substrate to "push against" while slithering upstream. For some higher barriers, elevator-style systems are also used.

An eel ladder typically consists of four parts: an *eel ascending ramp*, a *supporting structure*, a *water-feeding system*, and a *side gutter*. The side gutter provides an attraction flow to draw eels toward the ladder, the water-feeding system ensures the proper flow of water to the gutter and the ramp, and the supporting structure mounts the ladder to the barrier.

The **eel ascending ramp** can be a fairly simple constructions, such as a hollowed out tree filled with recycled fishing net, or a more complex structure designed to accommodate specific species or ages of eels. For example, the Canadian company Milieu Inc. manufactures eel ascending ramps made of moulded ABS with undulating side walls and staggered studs throughout the length of the ramp. These studs form the substrate the eels push against during the climb over the barrier.

Chapter- 6

Coastal Fish

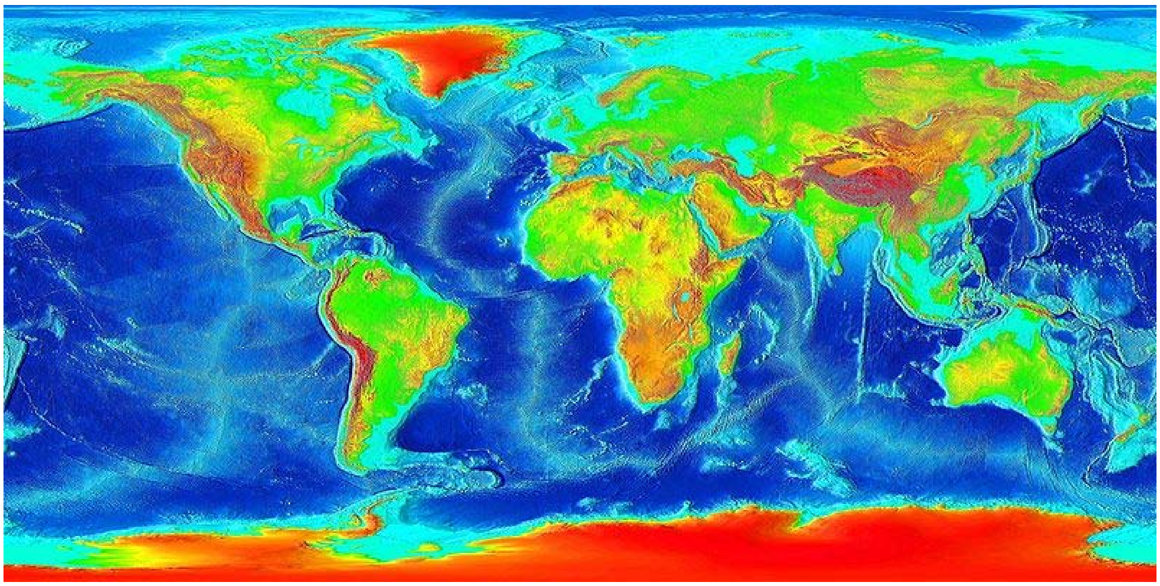


Schooling threadfin, a coastal species

Coastal fish, also called **offshore fish** or **neritic fish**, are fish that inhabit the sea between the shoreline and the edge of the continental shelf. Since the continental shelf is usually less than 200 metres deep, it follows that pelagic coastal fish are generally epipelagic fish, inhabiting the sunlit epipelagic zone. Coastal fish can be contrasted with ocean fish or offshore fish, which inhabit the oceans beyond the continental shelves.

Coastal fish are most abundant in the world. They can be found in tidal pools, fjords and estuaries, near sandy shores and rocky coastlines, around coral reefs and on or above the continental shelf. Coastal fish include forage fish as well as the predator fish that feed on them. Forage fish thrive in inshore waters where high productivity results from upwelling and shoreline run off of nutrients. Some are partial residents that spawn in streams, estuaries and bays, but most complete their life cycle in the zone.

Coastal habitats



The global continental shelf, highlighted in cyan

Coastal fish are found in the waters above the continental shelves that extend from the continental shorelines, and around the coral reefs that surround volcanic islands. The total world shoreline extends for 356,000 km (221,000 mi) and the continental shelves occupy a total area of 24.286 million km^2 (9 376 million sq mi). This is about 4.8% of the world's total area of 510.072 million km^2.

Nearshore fish

Nearshore fish, sometimes called **littoral fish**, live close to the shore. They are associated with the intertidal zone, or with estuaries, lagoons, coral reefs, kelp forests, seagrass meadows, or rocky or sandy bottoms, usually in shallow waters less than about 10 m deep.

Intertidal fish

The rise and fall of tides on a seashore defines an intertidal zone. It can be a volatile habitat for fish.

Intertidal fish are fish that move in and out with the tide in the intertidal zone of the seashore, or are found in rock pools or under rocks.

The intertidal zone of rocky shores can contain indentations which trap pools of salty water, called rock pools. Living in these habitats are communities of hardy plant and animal species specially adapted for coping with the volatile environment around them. The plants and animals interact with each other and with the rock pool to form miniature ecosystems, easily accessible to students and a source of fascination for young children. Plants such as sea anemones and seaweeds, and molluscs such as the common limpet, barnacles and the common periwinkle can be permanent residents of rock pools. But most rock pool animals, such as crabs, shrimp and fish are just temporary residents, occupying a rock pool only until the next tide takes them to a new location.

Some rock pool fish which are temporary residents include the long-spined sea scorpion, the pipefish worm, the rock goby and the common lumpsucker. However some other rock pool fish are territorial in nature, and will stay with the same pool for extended periods. Examples are the common blenny and its near relative the butterfish.

- The common blenny, also known as the shanny, are found in northern temperate waters. They hide under rocks and in crannies in rock pools when the tide is out. They feed on green seaweed and invertebrates such as barnacles. They can crawl on dry land, using their paired fins. About sixteen centimetres long, they have smooth skin, without scales, and are covered with soft slime. The slime prevents them drying if they are stranded on a shore between tides. So long as their skin stays moist they can breathe out of water. They are sometimes called "sea frogs" because they bask in the sun on weeds outside the water, and like frogs jump to safety when disturbed. They can change their colour to match their surroundings. The female lays eggs in crevices or under stones and the male guards them until they hatch. In the winter, when storms can be severe, they move out of their rock pools into the shallows. The common blenny is bold with strong teeth, and will bite humans if it feels threatened.

- The rock goby is a small fish, about 12 cm long, found in northern temperate waters. it is coloured black with white blotches, and hides under stones and amongst seaweed. It is a temporary resident of rock pools when the tide is out. The female rock goby lays eggs on the underside of rocks and shells and then leaves them. The male guards the eggs until they hatch. First year rock gobies often visit rock pools in winter when the older fish have left.

Australian blenny

Rock goby

Long-spined sea scorpion

Smooth lumpsucker inflated in a defensive response.

- The long-spined sea scorpion, a small stout fish which grows about 29 cm long, is another temporary resident of rocky pools. They have large black eyes, a large mouth, and four long spines—two on each side on the gill cover—that stick out when the fish is removed from the water. They also have an organ like a finger on each side of their mouth which helps them catch prey. Because of their broad heads, they are also called "bullheads". They have a variety of effective camouflaged colours ranging from shades of browns with cream blotches, to orange and red with white blotches. They can also change their body colour to match their surroundings. They are found around the coasts of Northern Europe in shallow rocky waters hiding amongst seaweed. They are also found in rock pools and sometimes in waters 30 m deep. Long-spined sea scorpions lay eggs amongst seaweed or attached to rock crevices. The young hatch after two or three weeks, and go through several development stages before maturing into adults.

- Lumpsuckers are found in temperate northern waters. They live on the seafloor, and are temporary residents of rocky pools in late winter and early spring when they spawn. The body of the lumpsucker is scaleless and covered with small lumps. They have a large sucking disc on their underside which they use to cling to surfaces. They are normally a blue to slate-grey colour, and are effectively camouflaged to look like stones. They are portly, nearly spherical, poor swimmers, reaching lengths up to 50 cm. After the female lumpsucker lays eggs, the male takes over, clamping itself to a rock where it guards the eggs. When they hatch, lumpsuckers look like tiny tadpoles. They remain in shallow water and rock pools, hiding amongst seaweed and rocks, until they grow up.

Estuarine fish

This estuary of the Klamath River is a transition zone between a freshwater river environment and a saltwater marine environment. Due to land runoff, river mouths and estuary waters can be turbid and nutrient rich, sometimes to the point of eutrophication.

Estuaries are partly enclosed coastal bodies of water with one or more rivers or streams flowing into them, and with a free connection to the open sea. These brackish water habitats form a transition zone between river environments and ocean environments, and ecological successions can form along the way. Estuaries are subject to both marine influences, such as tides, waves, and the influx of saline water; and riverine influences, such as flows of fresh water and sediment. The inflow of both seawater and freshwater provide high levels of nutrients in both the water column and sediment, making estuaries productive natural habitats.

Fishes that spend time in estuaries (or river mouths) need to be euryhaline (tolerant to a range of salinities). Estuaries provide an unstable environment for fish, where the salinity changes and the waters are often muddy and turbulent. In warmer climates, estuaries have mangroves around their edges. At times there may be only a few different fish species present in an estuary, but seasonal migrants, including eels, salmonids, and some forage fish such as herrings and sprats increase the diversity in the estuary.

River estuaries form important staging points during the migration of anadromous and catadromus fish species, such as salmon and eels, giving them time to form social groups and to adjust to the changes in salinity. Salmon are anadromous, meaning they live in the sea but ascend rivers to spawn; eels are catadromous, living in rivers and streams, but returning to the sea to breed. Besides the species that migrate through estuaries, there are many other fish that use them as "nursery grounds" for spawning or as places young fish can feed and grow before moving elsewhere. For example, herring and plaice are two commercially important species that use the Thames Estuary for this purpose.

Mangrove swamps are associated brackish water habitats. Many, though not all, mangrove swamps fringe estuaries and lagoons where the salinity changes with each tide. Among the most specialised residents of mangrove forests are mudskippers, fish that forage for food on land, and archer fish, perch-like fish that "spit" at insects and other small animals living in the trees, knocking them into the water where they can be eaten. Like estuaries, mangrove swamps are important breeding grounds for many fish, with species such as snappers, halfbeaks, and tarpon spawning or maturing among them.

Coral reef fish

Coral reefs support flourishing ecosystems, paradoxically in clear, low nutrient waters, along tropical continental coasts and around volcanic islands. Coral reef fish are numerous and diverse.

In tropical waters, coral reef fish live amongst or in close relation to coral reefs. Coral reefs form complex ecosystems with tremendous biodiversity. Coral reef fish can be particularly colourful and interesting to watch. Hundreds of species can exist in a small area of a healthy reef, many of them hidden or well camouflaged. Reef fish have developed many ingenious specialisations adapted to survival on the reefs. Coral reefs occupy less than one percent of the surface area of the world oceans, yet they provide a home for 25 percent of all marine fish species.

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

The sea goldie is an anthias. They are hermaphrodite, and swim in "harems"

Anthias are members of the family Serranidae (basses, basslets, groupers) and make up the subfamily Anthiinae. They are widespread in tropical waters. They have been called the "quintessential reef fish", and make up a sizeable portion of the colourful fishes seen swarming in coral reef photography. Anthias are mostly small, peaceful, beautiful and popular as ornamental fish. They are mainly zooplankton feeders. Anthias shoal and school in large numbers, operating more intimate "harems" within the schools. These harems contain a dominant and colourful male, between 2 and 12 females — who operate a hierarchy among themselves — and one or two "subdominant" males, often less brightly coloured and non-territorial. Within the swarm of females, territorial males perform acrobatic U-swim displays and vigorously defend an area of the reef and its associated harem. Anthias are protogynous hermaphrodites. All anthias are born female; if a dominant male perishes, the largest female of the group will often change into a male to take its place. This may lead to squabbling between the next largest male and the transforming female, whose hormones are now surging with testosterone. This can turn quite vicious in the limited confines of captivity.

The foureye butterflyfish has a false eyespot on its sides, which can confuse prey and predators.

Butterflyfish are group of about 120 species belonging to the family Chaetodontidaeof Perchiformes. They include bannerfish and coralfish. They are widespread on coral reefs. Butterflyfish are mostly between 12 and 22 centimetres (4.7 and 8.7 in) in length. The largest species, the lined butterflyfish and saddle butterflyfish, grow to 30 centimetres (12 in). Many species are brightly coloured and strikingly patterned, though other species are dull in colour. Many have eyespots on their flanks and dark bands across their eyes, not unlike the patterns seen on butterfly wings. Their deep, laterally narrow bodies are easily noticed through the profusion of reef life. The conspicuous colouration of butterflyfish may be intended for interspecies communication. Butterflyfish have uninterrupted dorsal fins with tail fins that may be rounded or truncated, but are never forked. Generally diurnal and frequenting waters of less than 18 metres (59 ft) (though some species descend to 180 metres (590 ft)), butterflyfish stick to particular home ranges. The corallivores are especially territorial, forming mated pairs and staking claim to a specific coral head. Contrastingly, the zooplankton feeders form large conspecific groups. By night butterflyfish hide in reef crevices and exhibit markedly different colouration. Their colouration also makes butterflyfish popular aquarium fish. However, most species feed on coral polyps and sea anemones, which can result in problems for the hobby aquarists.

Clownfish, anemonefish and damselfish are among about 360 species classified in the family Pomacentridae. Most Pomacentrids are associated with coral reefs in the Indo-West Pacific, with a few species occurring in temperate waters. Some species are native to freshwater or brackish estuarine environments. Most live in shallow water, from 2 to 15 meters (6 to 50 feet), although some species are found below 100 m (330 feet). Most species are specialists, living in specific parts of the reef, such as sandy lagoons, steep reef slopes, or areas exposed to strong wave action. In general, the coral is used as shelter, and many species can only survive in its presence. The bottom-dwelling species are territorial, occupying and defending a portion of the reef, often centred around an area of shelter. By keeping away other species of fish, some pomacentrids encourage the growth of thick mats of algae within their territories, leading to the common name farmerfish. Different species display a wide range of colours, although some are relatively drab. Pomacentrids are omnivorous or herbivorous, feeding off algae, plankton, and small bottom-dwelling crustaceans. A small number eat coral.

The yellowfin goatfish changes its colour so it can school with blue-striped snappers

Goatfishes are a family Mullidae of about 55 species of perciform fishes, associated worldwide with tropical reefs. They are typically about 20 cm long, though the dash-and-dot goatfish, grows to 55 cm. Goatfish are tireless benthic feeders, possess a pair of long chemosensory barbels ("whiskers") protruding from their chins resembling a goat's beard. They use these to rifle through the sediments in search of a meal. Like goats, they seek anything edible; worms, crustaceans, molluscs and other small invertebrates are staples. Many species of goatfish are conspicuously coloured and have the ability to change their colouration depending on their current activity. By day, many form large inactive (non-feeding) schools: these aggregates may contain both conspecifics and heterospecifics. For example, the yellowfin goatfish school with blue-striped snappers. When they do that, the yellowfins changes its colouration to match that of the snapper. By night the schools disperse and individual goatfish head their separate ways to loot the sands. The diurnal goldsaddle goatfish changes from a lemon-yellow to a pale cream when feeding. Other nocturnal feeders will shadow the active goatfish, waiting patiently for overlooked morsels. Goatfish stay within the shallows, going no deeper than about 110 metres. Most species do not tolerate brackish water, so they do not enter estuaries or the mouths of rivers.

Other nearshore fish

Kelp forests can provide shelter and food for shallow water fish

Other nearshore or shallow water fish live near the shore in depths of less than 10 metres. They occupy the areas over sandy or rocky bottoms, and can be associated with seagrass meadows and kelp forests. They can be divided into demersal fish and pelagic fish. Demersal fish live on or near the sea floor, while pelagic fish live in the water column away the sea floor.

Examples of such shallow water demersal fish, found in both tropical and temperate waters around the world, are triplefins, seahorses, wrasse and flounder. As demersal fish, all these fish spend most of their time on or near the sea floor.

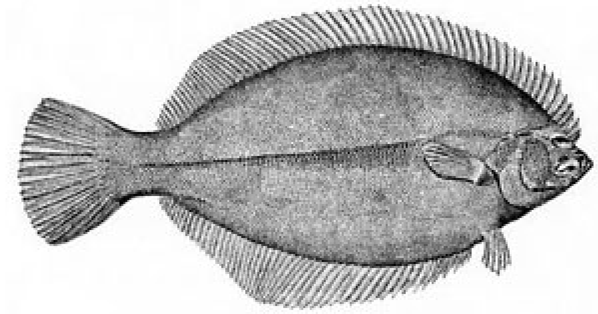
- Flatfish are superbly adapted groundfish, found on muddy and sandy sea floors. In many species both eyes lie on one side of the head, one or the other migrating through and around the head during development. Some species face their "left" side upward, some face their "right" side upward, and others face either side upward. Some flatfish can camouflage themselves on the ocean floor.

- Wrasse are a large family of mainly small fish, usually less than 20 centimetres (7.9 in) long. Most wrasse are loners that prefer habitats such as coral reefs and rocky shores. They live close to the substrate, eating small invertebrates and almost anything else that lurks on the bottom. Many are brightly coloured. They have thick lips and use their sharp teeth to pick small creatures off the rocks. Many smaller wrasses follow the feeding trails of larger fish, picking up invertebrates disturbed by their passing.

- Triplefins are a family of fish. They are usually found around coral reefs and rocks, usually in shallow, clear sunlit waters such as lagoons and seaward reefs. Triplefins have three dorsal fins (hence the name). They are small fish, usually less than six cm long. Brightly coloured, often for reasons of camouflage, they are nervous and retreat to rock crevices at any perceived threat.

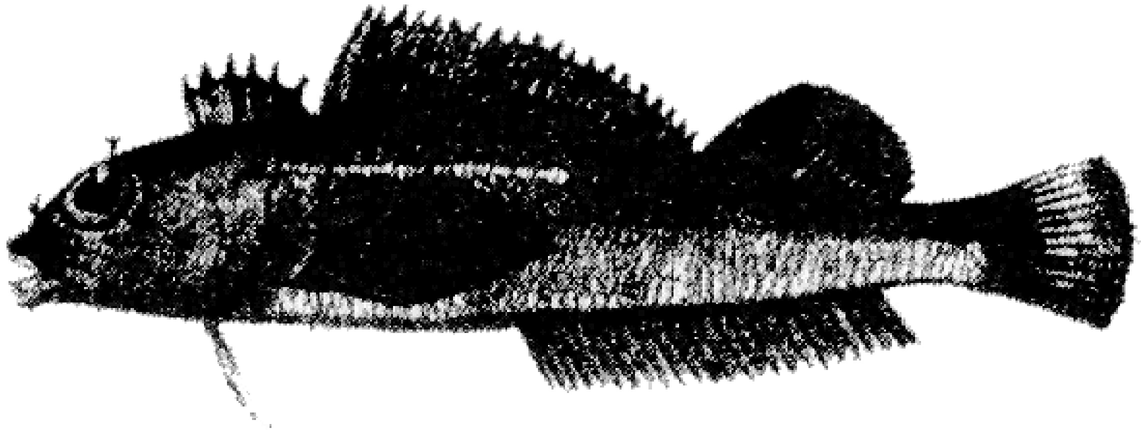
- Seahorses are a genus of fish. They prefer sheltered harbours, estuaries and other shallow coastal waters, where they hunts tiny crustaceans. They bob around in sheltered areas such as coral reefs, mangrove stands and seagrass meadows and estuaries. They are camouflaged with murky patterns that blend into kelp and sea grass backgrounds. During social moments or in unusual surroundings, seahorses can turn on bright colours.

Seahorse



Flatfish

Cleaner wrasses working on a dragon wrasse

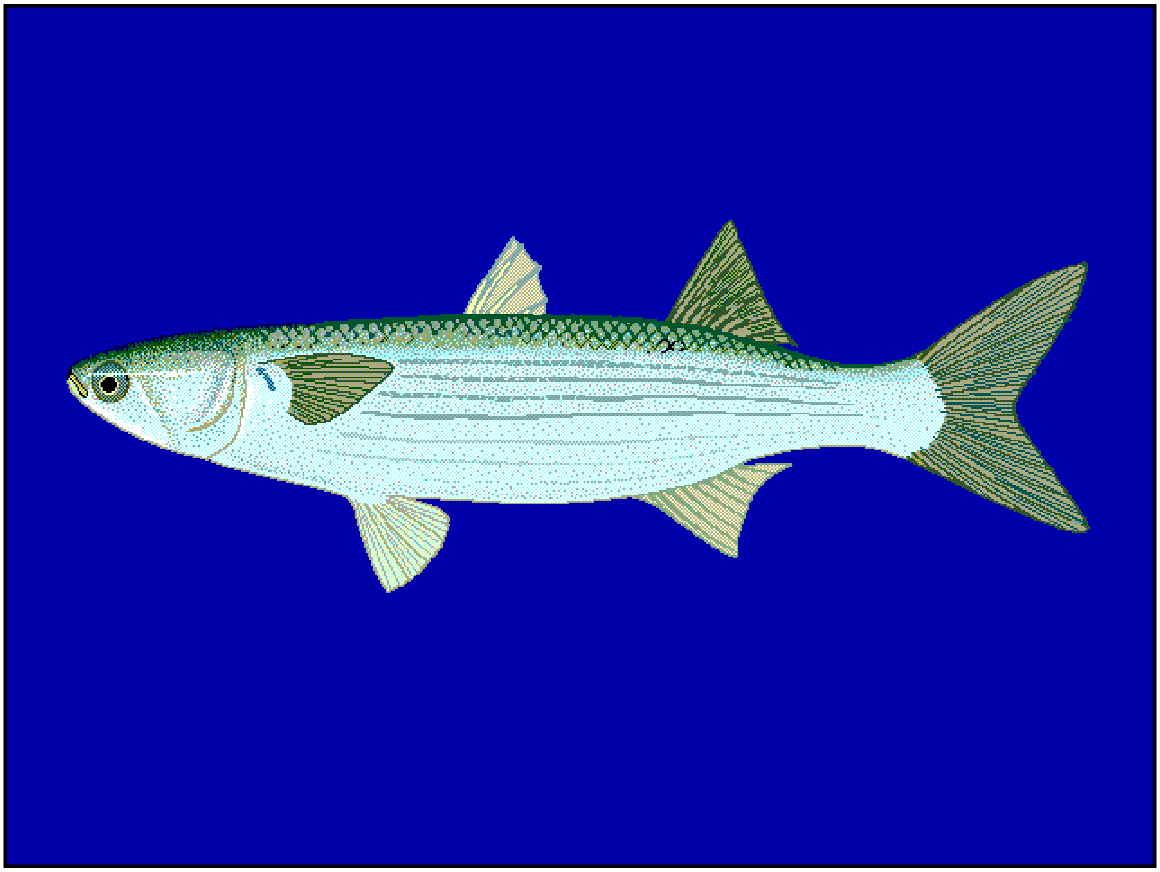


Common triplefin

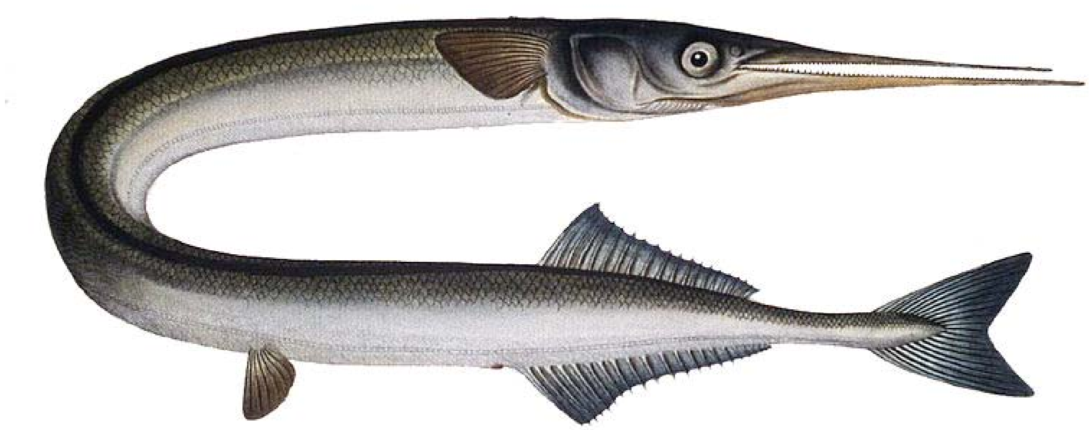
Examples of shallow water pelagic fish, found in both tropical and temperate waters around the world, are grey mullet, sprats and garfish. As pelagic fish, all these fish spend most of their time living in the water column away the sea floor.

- The grey mullet are medium size fish, typically about 50 cm (20 in) long. They are often caught with set nets.

- The garfish is a long, slender fish, looking like a spear, which feeds on seagrass fragments, shrimps and crab larvae. In turn it is preyed on by larger fish and, since it is often near the surface, cormorants and gannets.

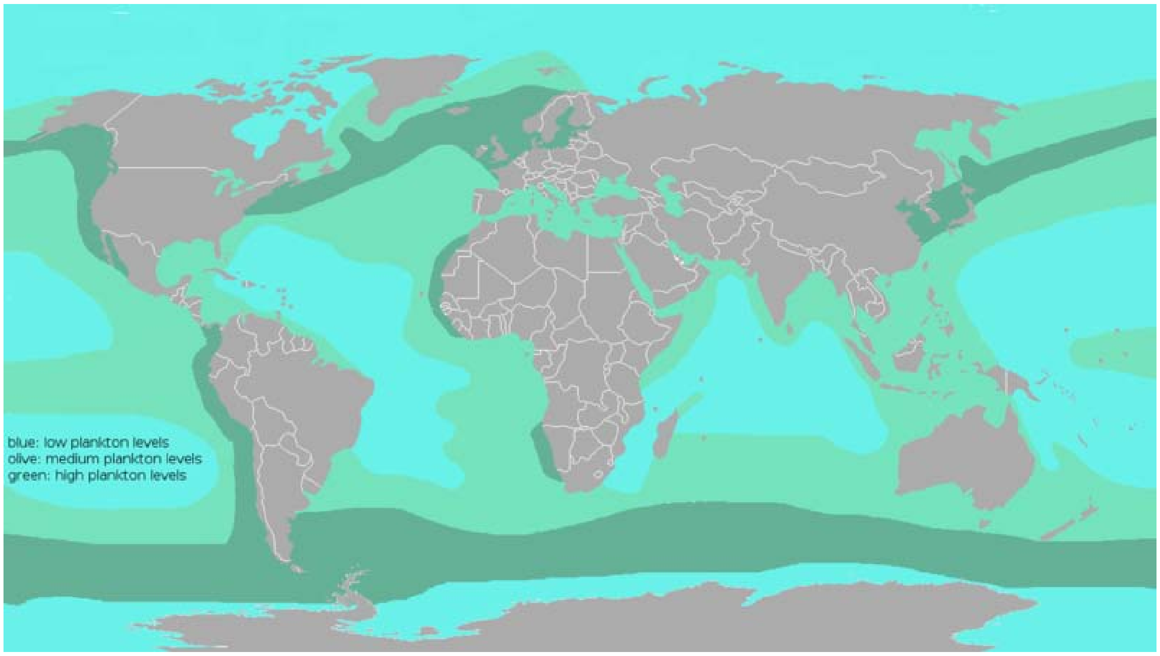


Grey mullet

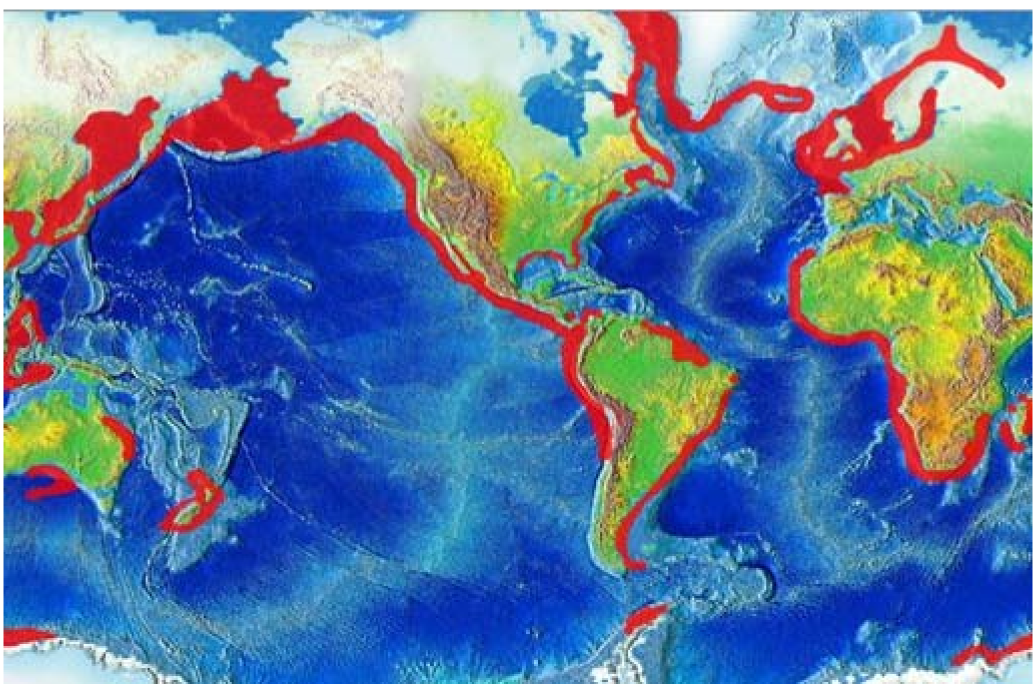


Garfish

Plankton feeding pelagic fish



World distribution of plankton



Areas of upwelling in red

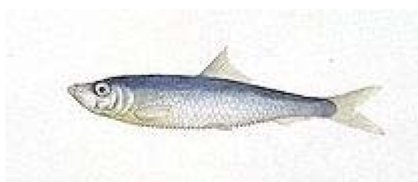
Plants are the base of food chains, and need sunlight and nutrients if they are to grow. In the ocean these plants are mainly a type of plankton, microscopic phytoplankton which drift in the water column. They need sunlight for photosynthesis, which powers carbon fixation, so they are found only in the surface waters. But they also need nutrients. Phytoplankton rapidly use any nutrients in the surface water.

The marine food chain starts with the primary producers, the phytoplankton. The phytoplankton are eaten by zooplankton, which in turn are eaten by predatory zooplankton. Filter feeders then eat the plankton and larger predatory fish eat the filter feeders.

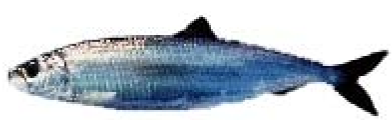
Most filter feeding pelagic fish found in coastal waters are small, silvery forage fish. Forage fish include fishes of the family Clupeidae (herrings, shad, sardines and pilchards, hilsa, menhaden and sprats), as well as anchovies, capelin and halfbeaks. They use schooling strategies to avoid predators, and different schools of forage fish often associate with each other in open coastal waters. Forage fish feed near the base of the food chain on plankton and fry (recently hatched fish), often by filter feeding. In turn, they are preyed on by larger predators, such as other larger fish, seabirds and marine mammals.

Worldwide, there are five major coastal currents associated with upwelling areas: the Canary Current (off Northwest Africa), the Benguela Current (off southern Africa), the California Current (off California and Oregon), the Humboldt Current (off Peru and Chile), and the Somali Current (off Western India). All of these currents support major fisheries. Many forage fish are important commercial species, and the schools can be targeted by spotter planes. The fish are caught by purse seiners—fishing boats that use nets to enclose the fish—and can be overfished.

Schooling anchovies



European sprat



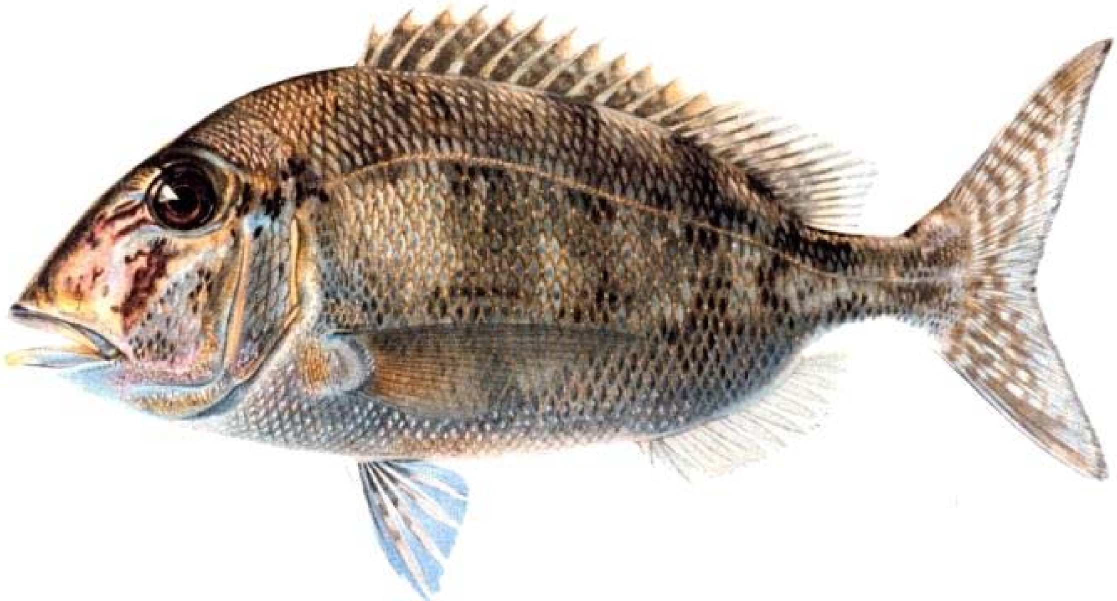
Atlantic herring

Predatory pelagic fish

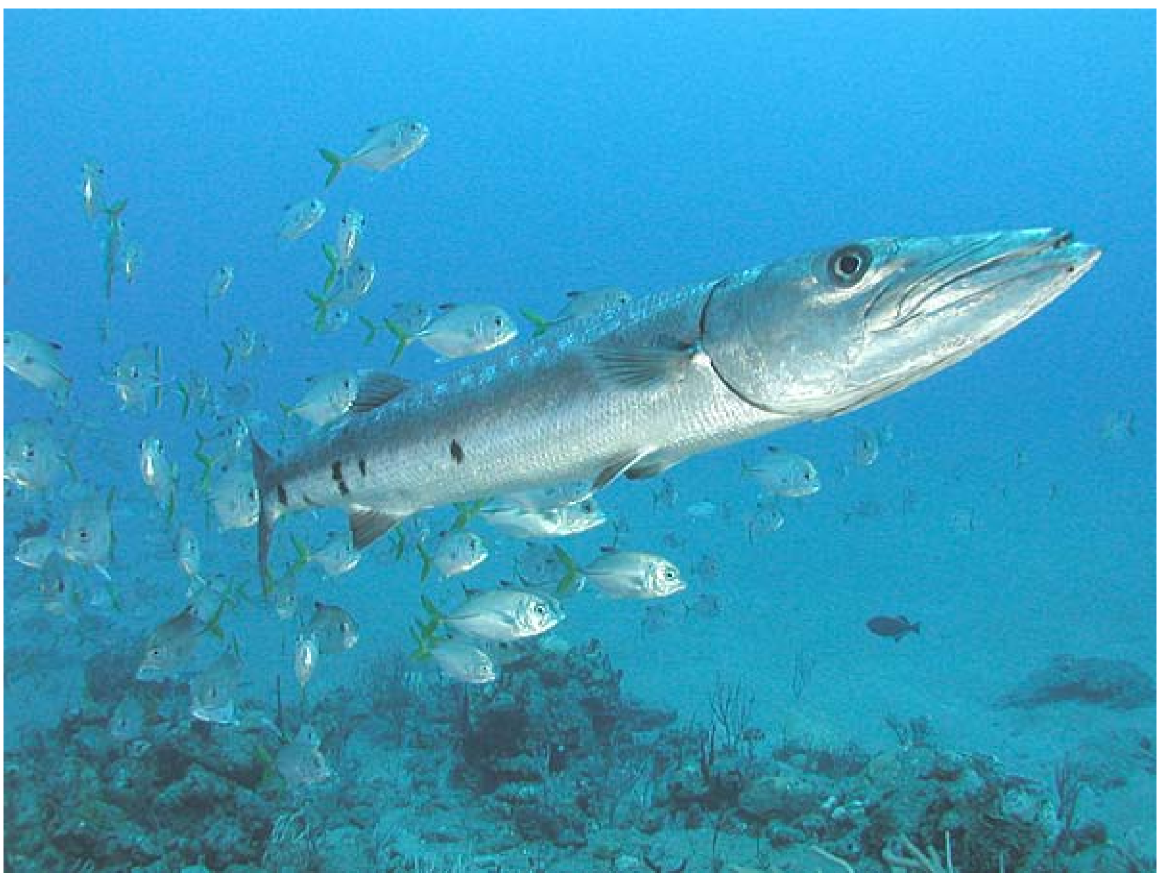
Predator bluefin trevally sizing up schooling anchovies

Predatory pelagic fishes found on continental shelves worldwide in both tropical and temperate waters include porgies, barracuda, amberjacks and cutlassfishes. They are carnivorous, feeding on smaller fish. Some species also feed on crabs and other invertebrates, foraged from the sea floor.

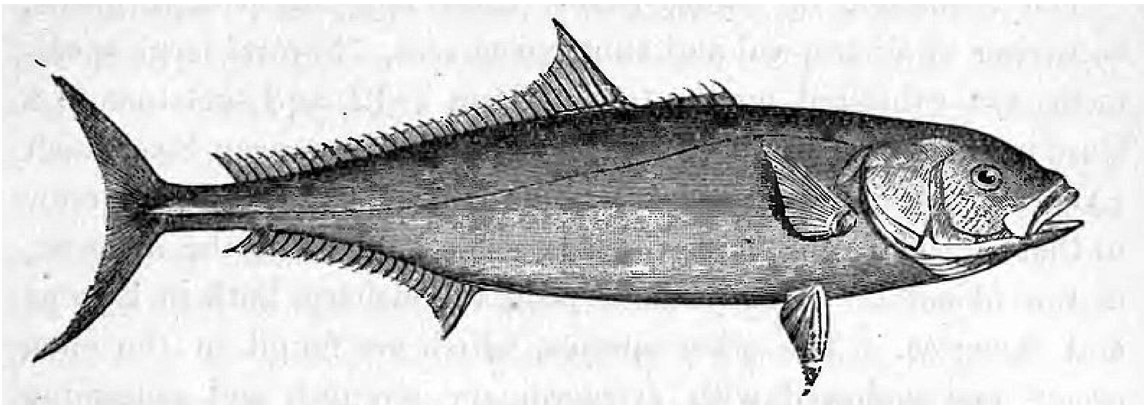
- Mackerel scom*
- Porgies sometimes called sea breams, are any of about 100 species belonging to the family Sparidae. Porgies usually have high backs and a single dorsal fin, like snapper or grunt fishes (grunts are named for the sound they make grinding their teeth). They are bottom feeding pelagic fishes, with small mouths equipped with strong teeth adapted for handling small fishes and invertebrates with hard shells. Most do not exceed a size of about 30 cm (12 in), but some may grow to four times that length. They often school, and will migrate between reefs. Larger fish enter estuaries and harbours.
- Barracuda have long slender bodies typically about 50 cm (20 in) long. They have a wicked set of teeth and are ferocious predators. They feed on crustaceans, cephalopods and small fish like anchovy and pilchard. Barracouta often hunt in schools near the bottom or midwater, and sometimes even near the surface at night.



The jolthead porgy is a porgi grunt

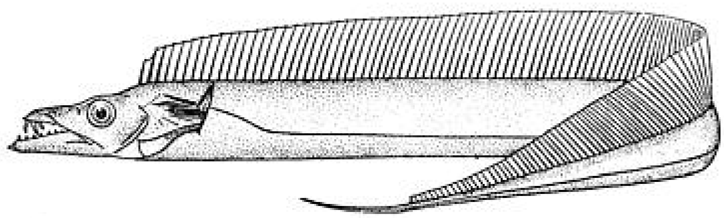


Great barracuda and jacks

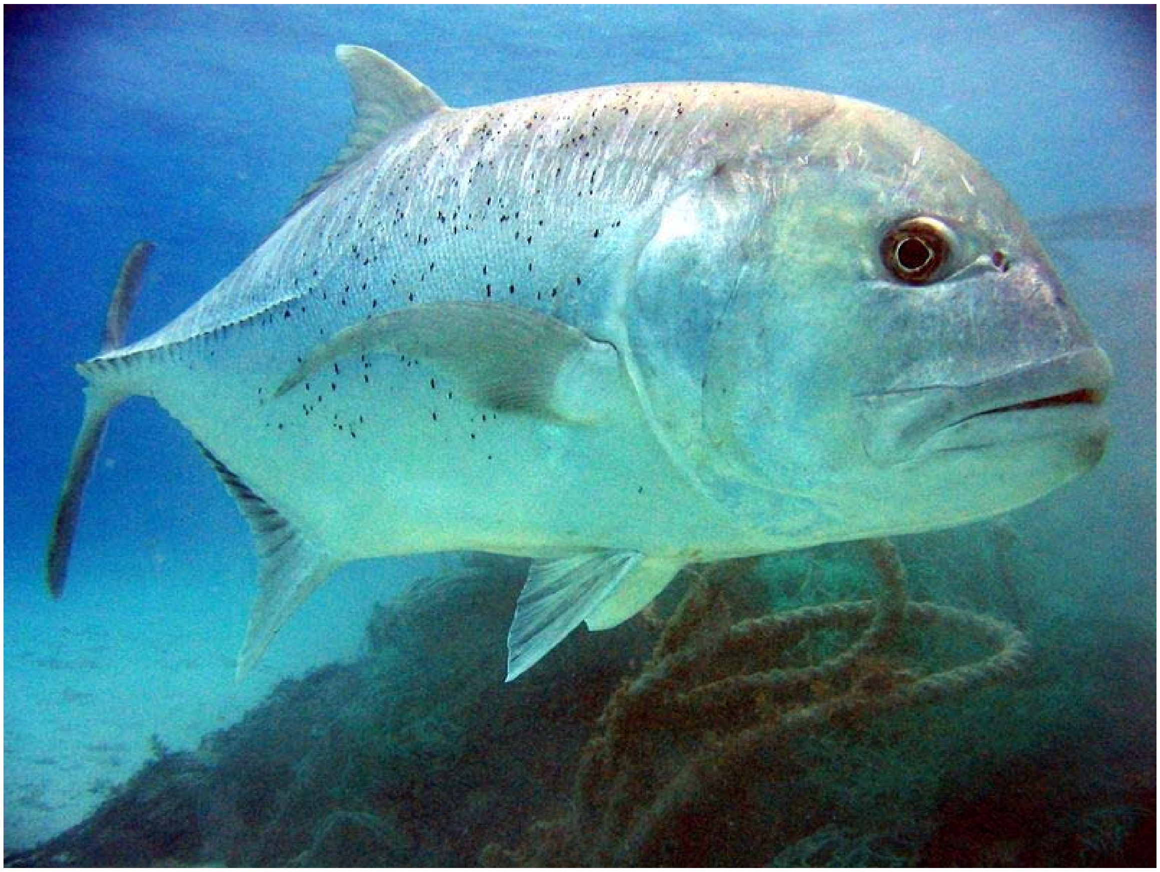


Yellow-tail (*Seriola lalandii*). (From South Australia.)

The yellowtail amberjack, pound for pound, is one of the hardest fighting fish in the ocean.



The largehead hairtail is a cutlassfish



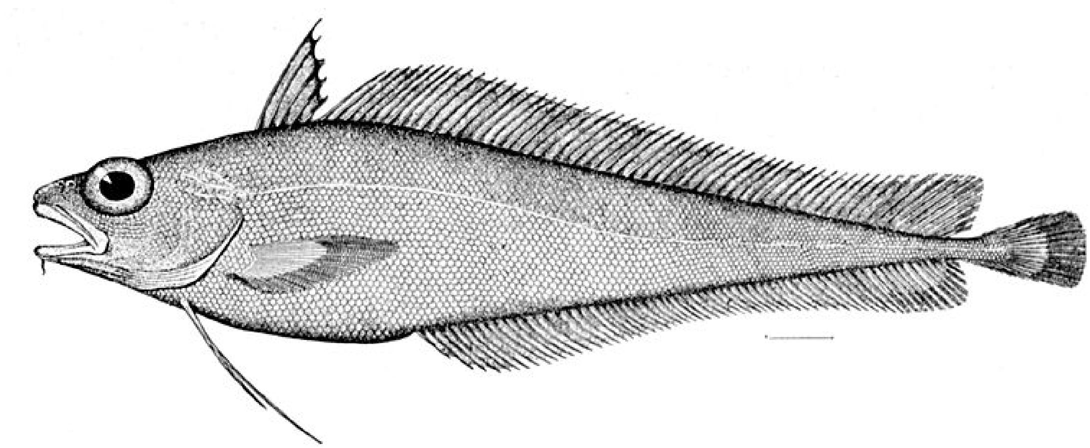
Giant trevally are great gamefish found in Indo-Pacific tropical waters. They are powerful apex predators in most of their habitats, hunting both individually and in schools.

- Cutlassfishes are a group of about 40 species belonging to the family Trichiuridae. They are ocean fish which regularly stray into coastal waters around the world. Fish of this family are long, slender, and generally steely blue or silver in colour, giving rise to their name. They have reduced or absent pelvic and caudal fins, giving them an eel-like appearance, and large fang-like teeth.

- Jacks, amberjacks, pompanos, horse mackerel, scads, leatherjackets and trevally are fish of the family *Carangidae*. Found in most coastal waters, they are fast predatory fishes that hunt in the waters above reefs and in the open sea; some dig in the sea floor for invertebrates (some can also filter feed, such as the white trevally). The largest fish in the family, the giant trevally, grows up to 1.7 m in length; most fish in the family reach a maximum length of 25–100 cm. The family contains many important commercial and game fish, notably the Pacific jack mackerel and the other jack mackerels in the genus *Trachurus*. The type species of this genus is the Atlantic horse mackerel. Jack mackerels are an important inshore commercial species.

- Amberjacks are a group of nine species belonging to the genus *Seriola* within the family Carangidae. Mainly open water fish, they can follow small forage fish into estuaries and enclosed waters, where they will also hunt for crustaceans. Amberjacks are fast swimming and aggressive predators that often hunt in schools around offshore reefs. the yellowtail amberjack can reach 1.8 metres in length and weigh 60 kilograms.

Demersal fish



Cod-like fishes, like this morid cod have a barbel (fleshy filament) on their lower jaw which they use to detect prey buried in the sand or mud.

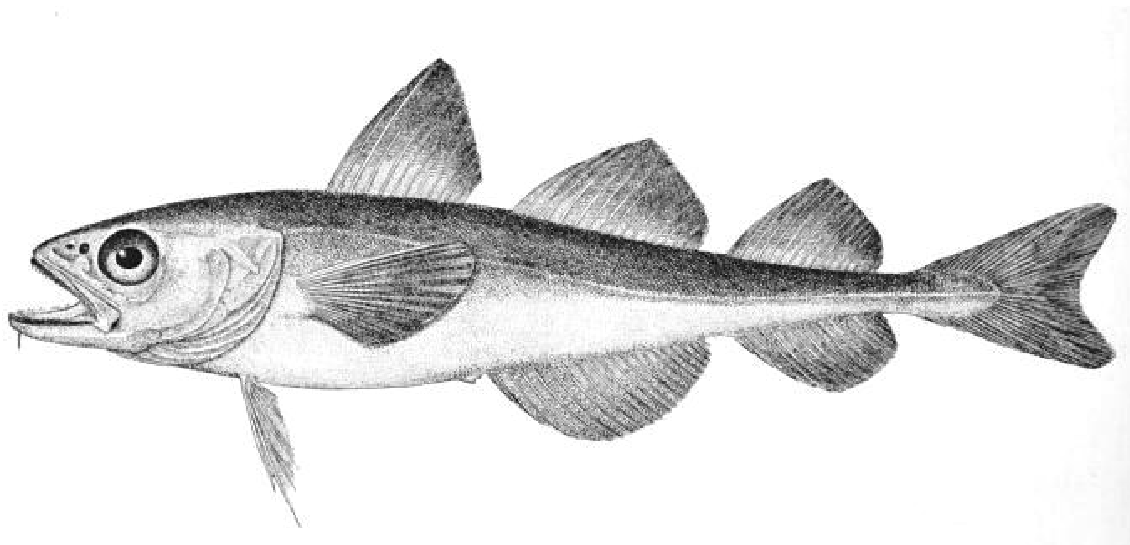
Fish that live on or in close association with the sea floor are called demersal fish. They are white fish. Unlike oily fish, white fish contain oils only in their liver, rather than in the gut, and can therefore be gutted as soon as they are caught, on board the ship. White fish has dry and white flesh. They are divided into round fish which live *near* the sea bed (cod, coley) and flatfish such as plaice which live *on* the sea bed.

This section discusses the demersal fish that live further from the coast and in deeper water than the nearshore fish discussed above.

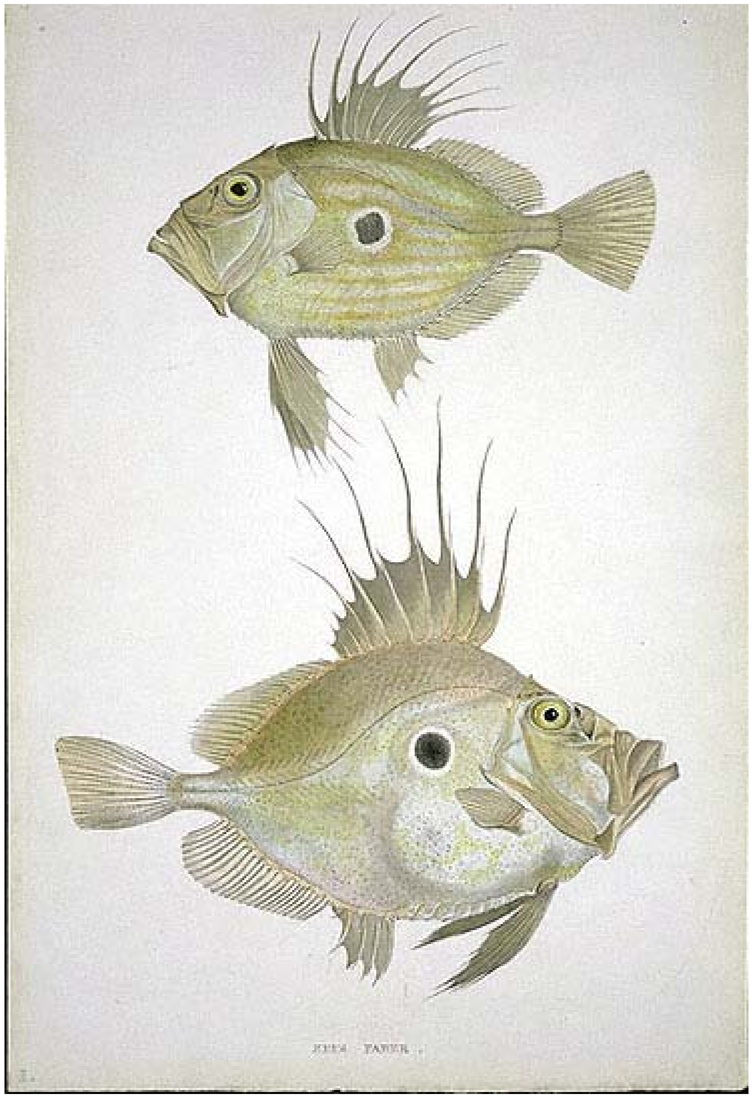
- Cod-like fishes are a number of benthopelagic species belonging to the order Gadiformes, such as Atlantic and Pacific cod, morid cod, haddock and pollock, including the highly commercial Alaska pollock. Cod-like fishes are often found in large schools over sandy or muddy bottoms. They have a barbel (fleshy filament) on their lower jaw which they use to detect prey buried in the sand or mud. Some migrate to warm water in winter to spawn.

- John dory are fishes of the genus *Zeus*. They have a widespread distribution and are typically found near the seabed in depths from 5 meters (15 ft). The John dory grows to a maximum length of 65 cm (2 ft). It has a flat, round body shape and can hardly be seen from the front because it is so thin. It is a poor swimmer with long spines on the dorsal fin. It has a large dark eyespot on the side of its body which is used to confuse prey, which are scooped up in its big mouth. Large eyes at the front of the head provide it with bifocal vision and depth perception, which are important for predators. The John Dory usually gets its food by stalking it then shooting out a tube in its mouth to capture its prey. It eats forage fish, and occasionally squid and cuttlefish. In turn, they are preyed on by sharks, like the dusky shark, and other large bony fish. They are normally solitary.

- Turbot and brill are flatfish, resembling flounder and sole, but found in deeper offshore waters on the continental shelf. They are brownish-green, with dark blotches on the turbot and mottling on the brill. They are fished by coastal trawlers.



The polar cod is found further north than any other fish species. It frequents river mouths and feeds on plankton and krill. It is preyed on by narwhals, belugas, ringed seals and seabirds.



The John dory is so thin it can hardly be seen from the front. The large eyespot on the side of its body confuses its prey.

The turbot is a large left-eyed flatfish usually found not too far from shore in sandy shallow waters. It is a prized food fish.

- Mail-cheeked fishes belong to a group of about 30 species in the order Scorpaeniformes. Mail-cheeked fishes are named after a plate of bone that runs across each cheek. The are widespread in all the oceans of the world. Mail-cheeked fishes are carnivorous, mostly feeding on crustaceans, such as crabs and shrimp, and on smaller fish. Most species live on the sea bottom in relatively shallow waters, although species are known from mid and deep water, from the mid-water, and even from fresh water. They typically have spiny heads, and rounded pectoral and caudal fins. Most species are less than 30 centimetres (12 in) in length, but the full size range of the order varies from the velvetfishes, which can be just 2 centimetres (0.79 in) long as adults, to the Lingcod, which can reach 150 centimetres (4.9 ft) in length.

    - Red gurnard are mail-cheeked fish. They use their large pectoral fins to rest on the bottom and to detect food.

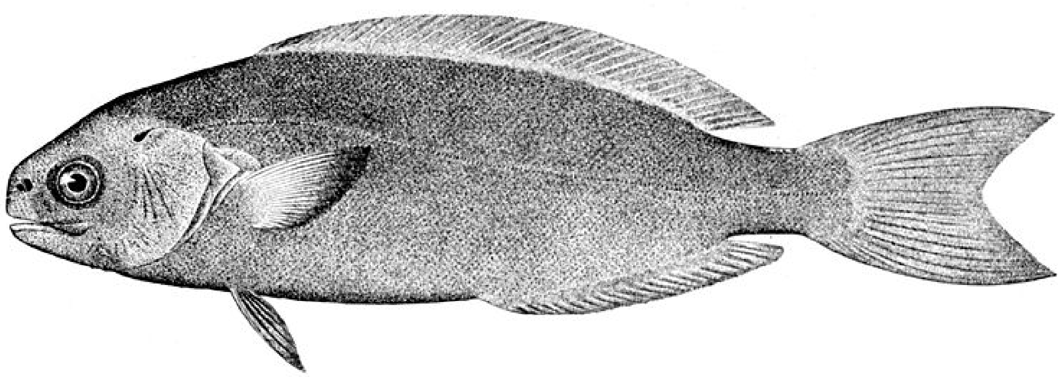
The stargazer is an ambush predator which can deliver both venom and electric shocks. It has been called "the meanest thing in creation".

Stargazers are about 50 species of fishes, belonging to the family Uranoscopidae, and found worldwide in shallow waters. Stargazers are venomous; they have two large poison spines situated behind the opercle and above the pectoral fins. They can also deliver electric shocks. They are ambush predators with eyes on top of their heads (thus the name). Stargazers also have a large upward-facing mouth in a large head. They bury themselves in sand with only their eyes showing, and leap upwards to ambush fish and invertebrates overhead. Some species have a worm-shaped lure growing out of the floor of the mouth, which they wiggle to attract prey's attention. Lengths range from 18 cm up to 90 cm, for the giant stargazer *Kathetostoma giganteum*. Stargazers are a delicacy in some cultures. The venom is destroyed when it is cooked, and stargazers are sold in some fish markets with their electric organ removed. They have been called "the meanest things in creation" and the "worst pet on earth".

- Sandperches are a family, Pinguipedidae, containing 63 species of fishes in the order Perciformes. They are benthic carnivoures, feeding on small fish and invertebrates. Examples are the redbanded weever, yellow weaver and blue cod. They are often caught in pots like crayfish.

- Medusa fishes are a family Centrolophidae of 31 species of perciform fishes. They are found in temperate and tropical waters throughout the world, usually feeding on fish, crustaceans and small squid near rough sea floors on continental shelf and slope. Examples are barrelfish, southern driftfish, imperial blackfish, the Japanese and pelagic butterfish, the New Zealand and Tasmanian ruffe, and the common, silver and white warehou. The young of some species associate with jellyfish, which provides them with protection from predators and opportunities to scavenge the remains of the jellyfish's meals. The young of other species associate with large masses of floating kelp.

A speckled sand perch perched on coral sand



The rudderfish is a medusa fish

Malabar grouper

Atlantic wreckfish inhabit caves and wrecks. They are good game fish, reaching a maximum reported length of 210 cm (7 ft) and weight of 100 kg (220 lb).

- Groper are fish belonging to a number of genera in the subfamily Epinephelinae of the family Serranidae, in the order Perciformes. Species of grouper include the black, comet, gag, giant, Goliath, Nassau, saddletail, tiger, Warsaw, white and yellowfin grouper. Typical lengths are 80–120 centimetres. They inhabit depths from reefs near the surface down to over 400 metres. They feed on just about any moving animal they encounter. Groper are important inshore commercial fish, usually caught with gill nets (in earlier times longlines were used).

- Wreckfish are a family Polyprionidae of perciform fishes, found on the floor of the continental shelf and slope where they inhabit caves and shipwrecks (thus their common name). The Atlantic wreckfish is at depths between 40 and 600 m (130 to 2,000 ft). They are largely a solitary fish, though juveniles school below floating objects. Their diet includes large ocean cephalopods, crustaceans, and other bottom-dwelling fishes.

Chapter- 7

Fish Migration

Many species of salmon are anadromous and migrate long distances up rivers and streams to spawn.

Many types of fish **migrate** on a regular basis, on time scales ranging from daily to annual, and over distances ranging from a few meters to thousands of kilometers. Fish usually migrate because of diet or reproductive needs, although in some cases the reason for migration remains unknown.

Classification

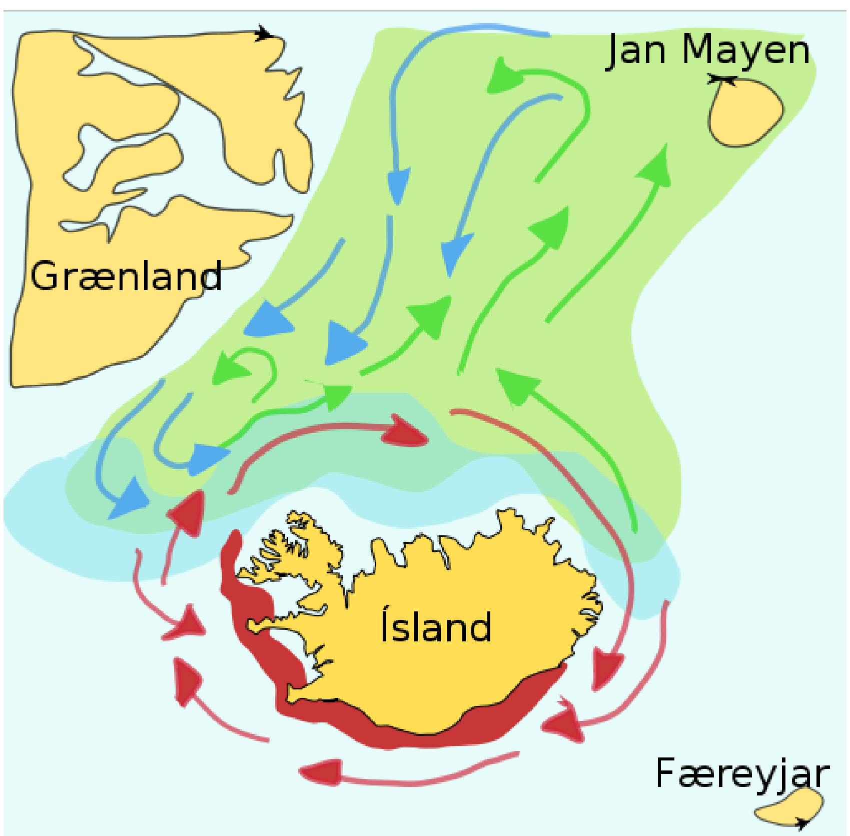
Fish can migrate vertically, up and down the water column, or horizontally, across oceans or along rivers. Many marine species make daily, or diel vertical migrations *(Latin: 'Dies' is day)*.

Classification of horizontally migrating fish:

- **potamodromous** fish migrate within fresh water only *(Greek: Potamos is river and dromos is 'a running')*.
- **oceanodromous** fish migrate within salt water only *(Greek: 'Oceanos' is ocean)*.
- **diadromous** fish travel between salt and fresh water *(Greek: 'Dia' is between)*.

    - **anadromous** fish live in the ocean mostly, and breed in fresh water *(Greek: 'Ana' is up; The noun is "anadromy")*
    - **catadromous** fish live in fresh water, and breed in the ocean *(Greek: 'Kata' is down)*
    - **amphidromous** fish move between fresh and salt water during their life cycle, but not to breed *(Greek: 'Amphi' is both)*

Forage fish



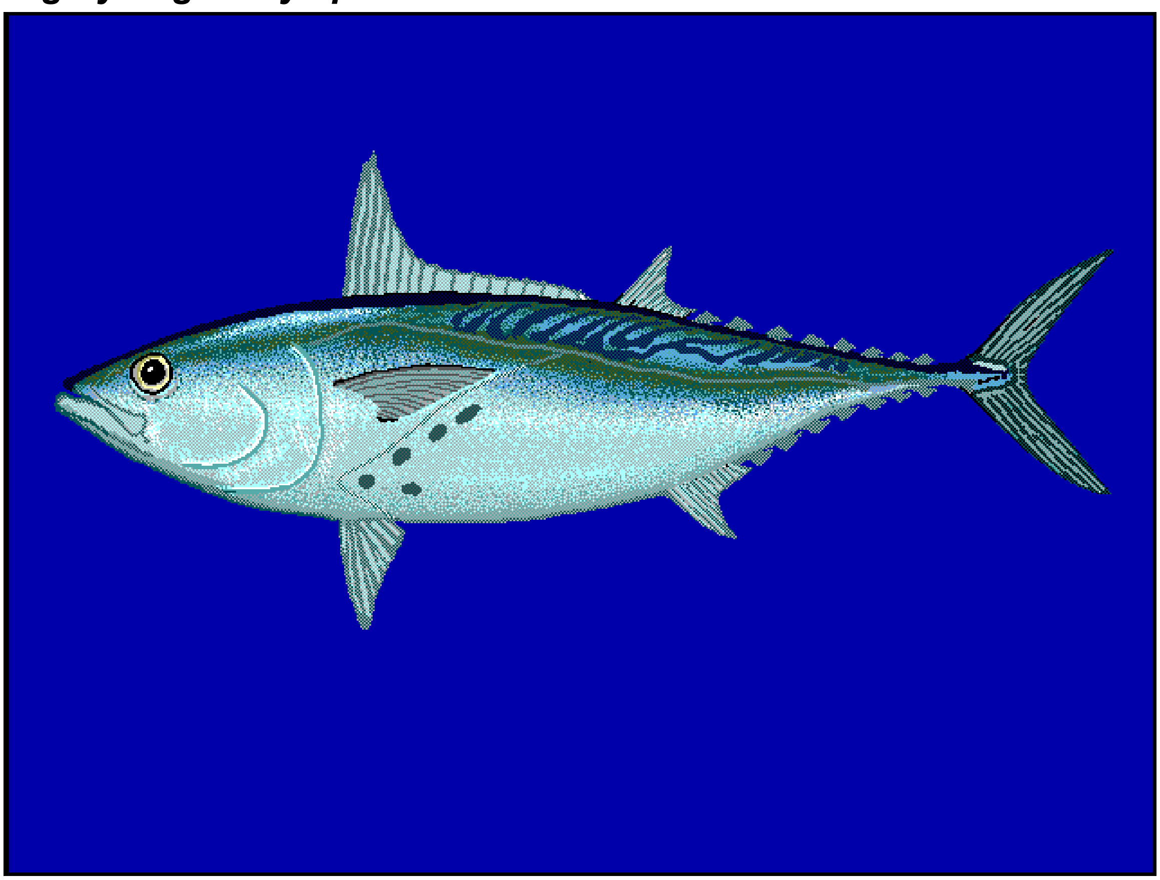
Migration of Icelandic capelin

Forage fish often make great migrations between their spawning, feeding and nursery grounds. Schools of a particular stock usually travel in a triangle between these grounds. For example, one stock of herrings have their spawning ground in southern Norway, their feeding ground in Iceland, and their nursery ground in northern Norway. Wide triangular journeys such as these may be important because forage fish, when feeding, cannot distinguish their own offspring.

Capelin are a forage fish of the smelt family found in the Atlantic and Arctic oceans. In summer, they graze on dense swarms of plankton at the edge of the ice shelf. Larger capelin also eat krill and other crustaceans. The capelin move inshore in large schools to spawn and migrate in spring and summer to feed in plankton rich areas between Iceland, Greenland, and Jan Mayen. The migration is affected by ocean currents. Around Iceland maturing capelin make large northward feeding migrations in spring and summer. The return migration takes place in September to November. The spawning migration starts north of Iceland in December or January.

The diagram on the right shows the main spawning grounds and larval drift routes. Capelin on the way to feeding grounds is coloured green, capelin on the way back is blue, and the breeding grounds are red.

Highly migratory species



Little tunny

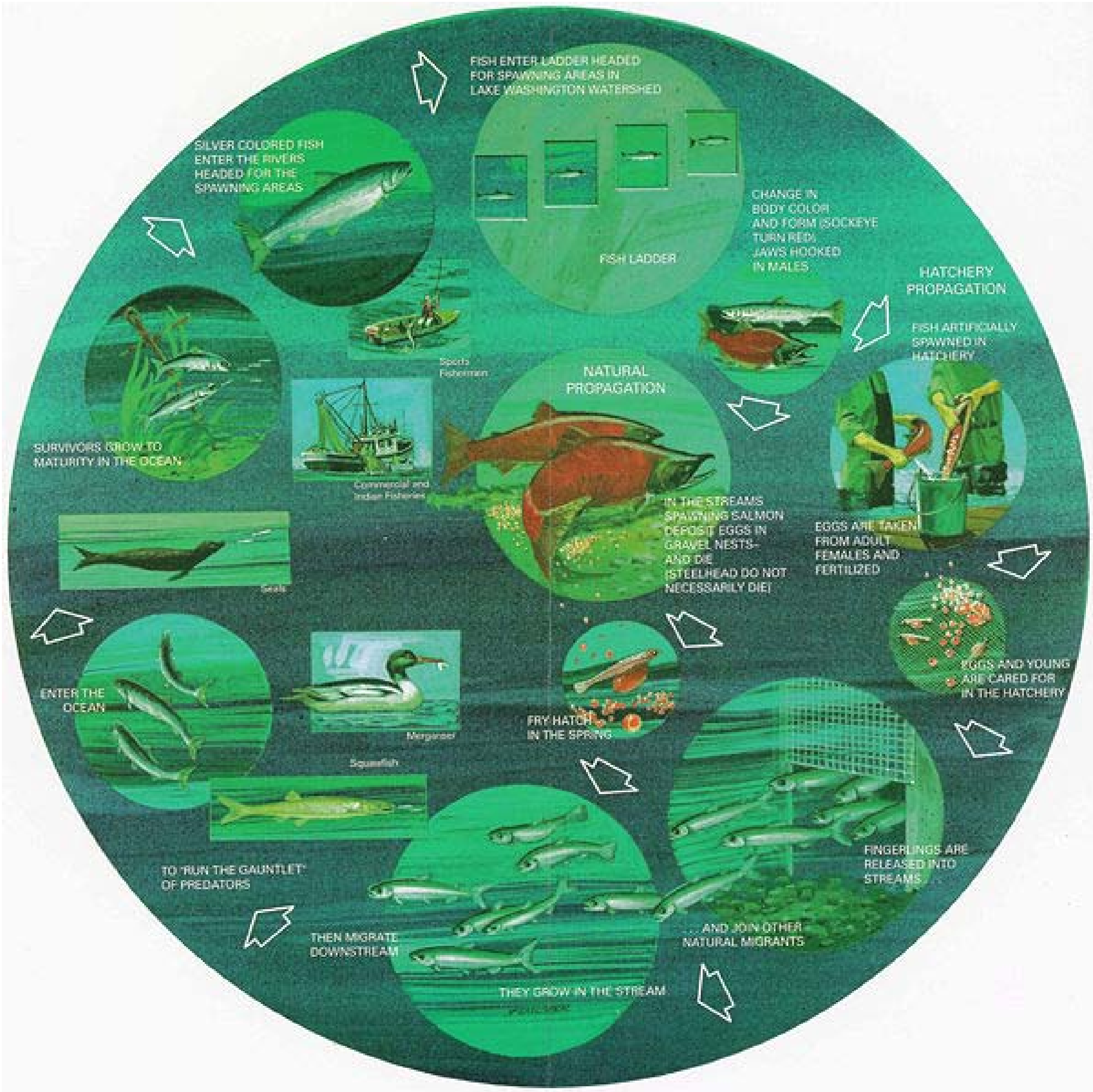
The term **highly migratory species** (HMS) has its origins in Article 64 of the United Nations Convention on the Law of the Sea (UNCLOS). The Convention does not provide an operational definition of the term, but in an annex (UNCLOS Annex 1) lists the species considered highly migratory by parties to the Convention. The list includes: tuna and tuna-like species (albacore, bluefin, bigeye tuna, skipjack, yellowfin, blackfin, little tunny, southern bluefin and bullet), pomfret, marlin, sailfish, swordfish, saury and ocean going sharks, dolphins and other cetaceans.

These high trophic oceanodromous species undertake migrations of significant but variable distances across oceans for feeding, often on forage fish, or reproduction, and also have wide geographic distributions. Thus, these species are found both inside the 200 mile exclusive economic zones and in the high seas outside these zones. They are pelagic species, which means they mostly live in the open ocean and do not live near the sea floor, although they may spend part of their life cycle in nearshore waters.

Highly migratory species can be compared with straddling stock and transboundary stock. Straddling stock range both within an EEZ as well as in the high seas. Transboundary stock range in the EEZs of at least two countries. A stock can be both transboundary and straddling.

Other examples

Some of the best-known anadromous fish are the six species of Pacific salmon, which are Chinook (King), Coho (Silver), Sockeye (Red), Chum (Dog), Pink (Humpback), and Cherry. The salmon hatch in small freshwater streams. From there they migrate to the sea to mature, living there for two to six years. When mature, the salmon return to the same streams where they were hatched to spawn. Salmon are capable of going hundreds of kilometers upriver, and humans must install fish ladders in dams to enable the salmon to get past. Other examples of anadromous fishes are sea trout, three-spined stickleback, and shad.



Life cycle of anadromous fish. From a U.S. Federal Government pamphlet.

The most remarkable catadromous fishes are freshwater eels of genus *Anguilla*, whose larvae drift from swawning grounds in the Sargasso sea, sometimes for months or years, before entering freshwater river and streams as glass eels or elvers.

An example of an amphidromous species is the Bull shark, which lives in Lake Nicaragua of Central America and the Zambezi River of Africa. Both these habitats are fresh water, yet Bull sharks will also migrate to and from the ocean. Specifically, Lake Nicaragua Bull sharks migrate to the Atlantic Ocean and Zambezi Bull sharks migrate to the Indian Ocean.

Diel vertical migration is a common behavior; many marine species move to the surface at night to feed, then return to the depths during daytime.

A number of large marine fishes, such as the tuna, migrate north and south annually, following temperature variations in the ocean. These are of great importance to fisheries.

Freshwater fish migrations are usually shorter, typically from lake to stream or vice versa, for spawning purposes. However, potamodromous migrations of Colorado pikeminnow of the Colorado River system can be extensive. Migrations to natal spawning grounds easily be 100 km, with maximum distances of 300 km reported from radiotagging studies.

Historic exploitation

Since prehistoric times humans have exploited certain anadromous fishes during their migrations into freshwater streams, when they are more vulnerable to capture. Societies dating to the Millingstone Horizon are known which exploited the anadromous fishery of Morro Creek and other Pacific coast estuaries. In Nevada the Paiute tribe has harvested migrating Lahontan cutthroat trout along the Truckee River since prehistoric times. This fishing practice continues to current times, and the U.S. Environmental Protection Agency has supported research to assure the water quality in the Truckee can support suitable populations of the Lahontan cutthroat trout.

Modelling fish migration

In a paper published in 2009, researchers from Iceland recount their application of an interacting particle model to the capelin stock around Iceland, successfully predicting the spawning migration route for 2008.

Chapter- 8

Forage Fish

School of goldband fusiliers

Forage fish, also called **prey fish**, are small fish which are preyed on by larger predators for food. Predators include other larger fish, seabirds and marine mammals. Typical ocean forage fish feed near the base of the food chain on plankton, often by filter feeding. They include the fishes of the family Clupeidae (herrings, shad, sardines, hilsa, menhaden and sprats), as well as anchovies, capelin and halfbeaks.

Forage fish compensate for their small size by forming schools. Some swim in synchronised grids with their mouths open so they can efficiently filter plankton. These schools can become immense shoals which move along coastlines and migrate across open oceans. The shoals are concentrated fuel resources for the great marine predators. The predators are keenly focused on the shoals, acutely aware of their numbers and whereabouts, and make migrations themselves that can span thousands of miles to connect, or stay connected, with them.

The ocean primary producers, mainly contained in plankton, produce food energy from the sun and are the raw fuel for the ocean food webs. Forage fish transfer this energy by eating the plankton and becoming food themselves for the top predators. In this way, forage fish occupy the central positions in ocean and lake food webs.

In recent times, many of the worlds great predator fisheries have collapsed. To compensate, the fishing industry is removing huge amounts of forage fish from the oceans, using factory ships with sophisticated sonar and spotting planes. Most of the catch is fed to farmed animals. Fisheries scientists are expressing concern that this will result in further collapses of the predator fish that depend on them.

In the oceans

Typical ocean forage fish are small, silvery schooling oily fish such as herring, anchovies and menhaden, and other small, schooling baitfish like capelin, smelts, sand lance, halfbeaks, pollock, butterfish and juvenile rockfish. Herrings are a preeminent forage fish, often marketed as sardines or pilchards.

The term “forage fish” is a term used in fisheries, and is applied also to forage species that are not true fish, but play a significant role as prey for predators. Thus invertebrates such as squid and shrimp are also referred to as "forage fish". Even the tiny shrimp-like creatures called krill, small enough to be eaten by other forage fish, yet large enough to eat the same zooplankton as forage fish, are often classified as "forage fish".

Ocean forage fish

Anchovies

Caribbean reef squid

Menhaden

Sardines

Shrimp

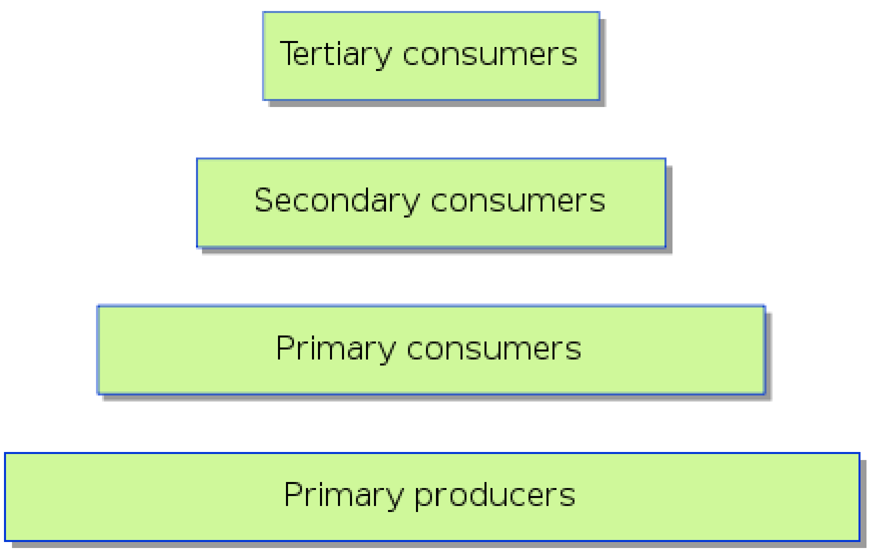
Northern krill

Forage fish utilise the biomass of copepods, mysids and krill in the pelagic zone to become the dominant converters of the enormous ocean production of zooplankton. They are, in turn, central prey items for higher trophic levels. Forage fish may have achieved their dominance because of the way they live in huge, and often extremely fast cruising schools.

Though forage fish are abundant, there are relatively few species. There are more species of primary producers and apex predators in the ocean than there are forage fish.

Ocean food webs

Forage fish occupy central positions in the ocean food webs. The position that a fish occupies in a food web is called its trophic level (Greek *trophē* = food). The organisms it eats are at a lower trophic level, and the organisms that eat it are at a higher trophic level. Forage fish occupy middle levels in the food web, serving as a dominant prey to higher level fish, seabirds and mammals.

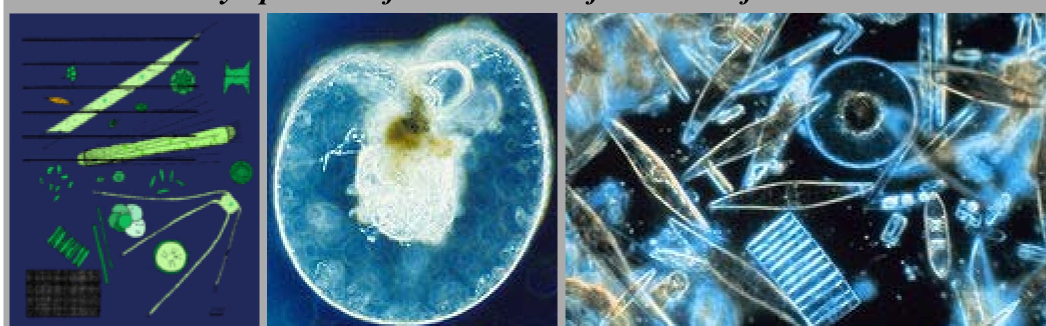


Ecological pyramids are graphical representations, along the lines of the diagram at the right, which show how biomass or productivity changes at each trophic level in a ecosystem. The first or bottom level is occupied by primary producers or autotrophs (Greek *autos* = self and *trophe* = food). These are the names given to organisms that do not feed on other organisms, but produce biomass from inorganic compounds, mostly by a process of photosynthesis.

In oceans, most primary production is performed by algae. This is a contrast to land, where most primary production is performed by vascular plants. Algae ranges from single floating cells to attached seaweeds, while vascular plants are represented in the ocean by groups such as the seagrasses. Larger producers, such as seagrasses and seaweeds, are mostly confined to the littoral zone and shallow waters, where they attach to the underlying substrate and still be within the photic zone. Most primary production in the ocean is performed by microscopic organisms, the phytoplankton.

Thus, in ocean environments, the first bottom trophic level is occupied principally by phytoplankton, microscopic drifting organisms, mostly one-celled algae, that float in the sea. Most phytoplankton are too small to be seen individually with the unaided eye. They can appear as a green discoloration of the water when they are present in high enough numbers. Since they increase their biomass mostly through photosynthesis they live in the sun-lit surface layer (euphotic zone) of the sea.

Phytoplankton form the base of the ocean foodchain

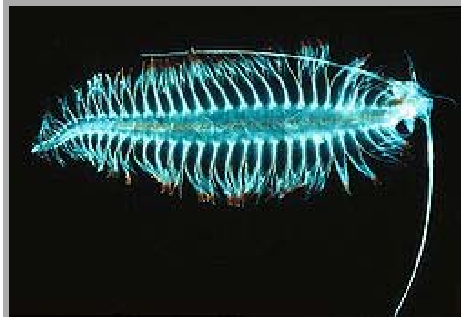


Phytoplankton **Dinoflagellate** **Diatoms**

The most important groups of phytoplankton include the diatoms and dinoflagellates. Diatoms are especially important in oceans, where they are estimated to contribute up to 45% of the total ocean's primary production. Diatoms are usually microscopic, although some species can reach up to 2 millimetres in length.

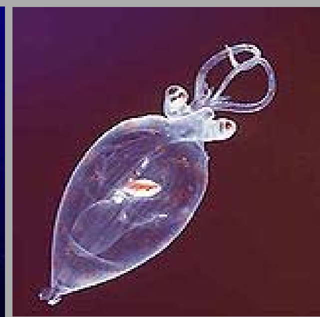
The second trophic level (primary consumers) is occupied by zooplankton which feed off the phytoplankton. Together with the phytoplankton, they form the base of the food pyramid that supports most of the world's great fishing grounds. Zooplankton are tiny animals found with the phytoplankton in oceanic surface waters, and include tiny crustaceans, and fish larvae and fry (recently-hatched fish). Most zooplankton are filter feeders, and they use appendages to strain the phytoplankton in the water. Some larger zooplankton also feed on smaller zooplankton. Some zooplankton can jump about a bit to avoid predators, but they can't really swim. Like phytoplankton, they float with the currents, tides and winds instead. Zooplanktons can reproduce rapidly, their populations can increase up to thirty percent a day under favourable conditions. Many live short and productive lives and reach maturity quickly.

Zooplankton form the second level in the ocean food chain



Segmented worm

Tiny shrimp-like crustaceans



Juvenile planktonic squid

Particularly important groups of zooplankton are the copepods and krill. These are not shown in the images above, but are discussed in more detail later. Copepods are a group of small crustaceans found in ocean and freshwater habitats. They are the biggest source of protein in the sea, and are important prey for forage fish. Krill constitute the next biggest source of protein. Krill are particularly large predator zooplankton which feed on smaller zooplankton. This means they really belong to the third trophic level, secondary consumers, along with the forage fish.

Together, phytoplankton and zooplankton make up most of the plankton in the sea. Plankton is the term applied to any small drifting organisms that float in the sea (Greek *planktos* = wanderer or drifter). By definition, organisms classified as plankton are unable to swim against ocean currents; they cannot resist the ambient current and control their position. In ocean environments, the first two tropic levels are occupied mainly by plankton. Plankton are divided into producers and consumers. The producers are the phytoplankton (Greek *phyton* = plant) and the consumers, who eat the phytoplankton, are the zooplankton (Greek *zoon* = animal).

Diet

Forage fish feed on plankton. When they are eaten by larger predators, they transfer this energy from the bottom of the food chain to the top and in this way are the central link between trophic levels.

Forage fish are usually filter feeders, meaning that they feed by straining suspended matter and food particles from water. They usually travel in large, slow moving, tightly packed schools with their mouths open. They are typically omnivorous. Their diet is usually based primarily on zooplankton, although, since they are omnivorous, they also take in some phytoplankton.

Young forage fish, such as herring, mostly feed on phytoplankton and as they mature they start to consume larger organisms. Older herrings feed on zooplankton, tiny animals that are found in oceanic surface waters, and fish larvae and fry (recently-hatched fish). Copepods and other tiny crustaceans are common zooplankton eaten by forage fish.

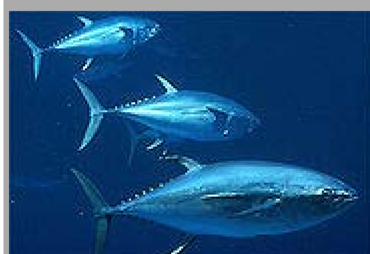
During daylight, many forage fish stay in the safety of deep water, feeding at the surface only at night when there is less chance of predation. They swim with their mouths open, filtering plankton from the water as it passes through their gills.

Ocean halfbeaks are omnivores which feed on algae, plankton, marine plants like seagrass, invertebrates like pteropods and crustaceans and smaller fishes. Some tropical species feed on animals during the day and plants at night, while others alternate summer carnivory with winter herbivory. They are in turn eaten by billfish, mackerel, and sharks.

Predators

Forage fish are the food that sustains larger predators above them in the ocean food chain. The superabundance they present in their schools make them ideal food sources for top predator fish such as tuna, striped bass, cod, salmon, barracuda and swordfish, as well as sharks, whales, dolphins, porpoises, seals, sea lions, and seabirds.

Ocean predators of forage fish



Tuna

Shark

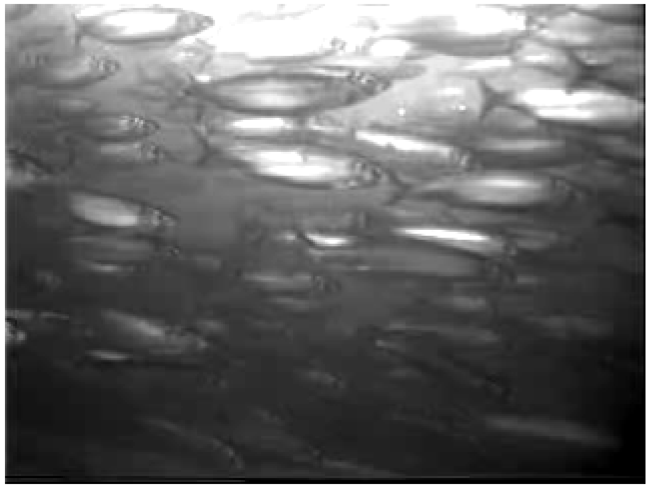
Striped bass

Leopard seal

Dolphin

Gannet

Schooling



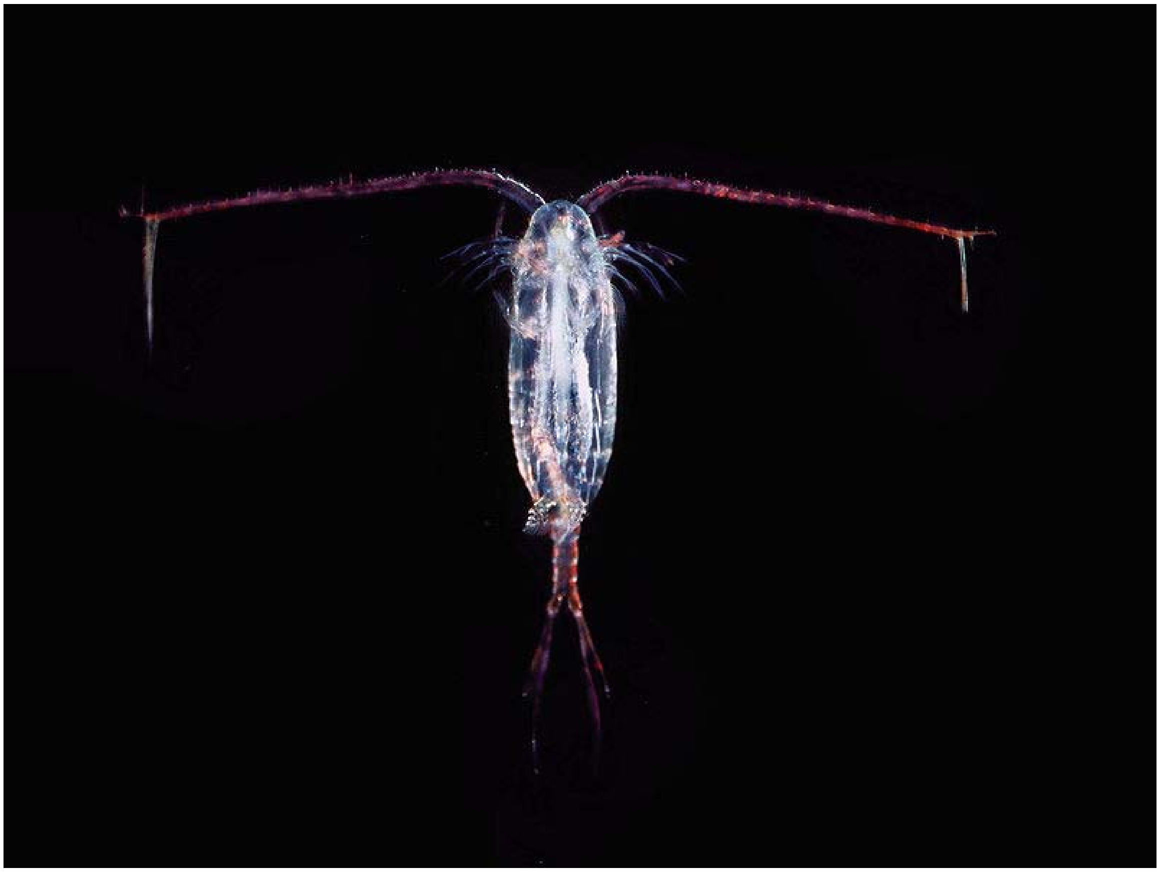
A school of herrings migrating at high speed to their spawning grounds in the Baltic Sea

Forage fish compensate for their small size by forming schools. These sometimes immense gatherings fuel the ocean food web. Most forage fish are pelagic fish, which means they form their schools in open water, and not on the bottom (benthic fish) or near the bottom (benthopelagic fish). They are short-lived, and go mostly unnoticed by humans, apart from an occasional support role in a documentary about a great ocean predator. While we may not pay them much attention, the great marine predators are keenly focused on them, acutely aware of their numbers and whereabouts, and make migrations that can span thousands of miles to connect with them. After all, forage fish are their food.

Herring are among the most spectacular schooling fish. They aggregate together in huge numbers. Schools have been measured up to four cubic kilometres in size, containing about four billion fish. These schools move along coastlines and traverse the open oceans. Herring schools in general have very precise arrangements which allow the school to maintain relatively constant cruising speeds. Herrings have excellent hearing, and their schools react very fast to a predator. The herrings keep a certain distance from a moving scuba diver or cruising predator like a killer whale, forming a vacuole which can look like a doughnut from a spotter plane. The intricacies of schooling is far from fully understood, especially the swimming and feeding energetics. Many hypotheses to explain the function of schooling have been suggested, such as better orientation, synchronized hunting, predator confusion and reduced risk of being found. Schooling also has disadvantages, such as excretion buildup in the breathing media and oxygen and food depletion. The way the fish array in the school probably gives energy saving advantages, though this is controversial.

On calm days, schools of herring can be detected at the surface a mile away by little waves they form, or from several meters at night when they trigger bioluminescence in surrounding plankton. Underwater recordings show herring constantly cruising at high speeds up to 108 cm per second, with much higher escape speeds.

They are fragile fish, and because of their adaptation to schooling behaviour they are rarely displayed in aquaria. Even with the best facilities aquaria can offer they become sluggish compared to their quivering energy in wild schools.



Copepod

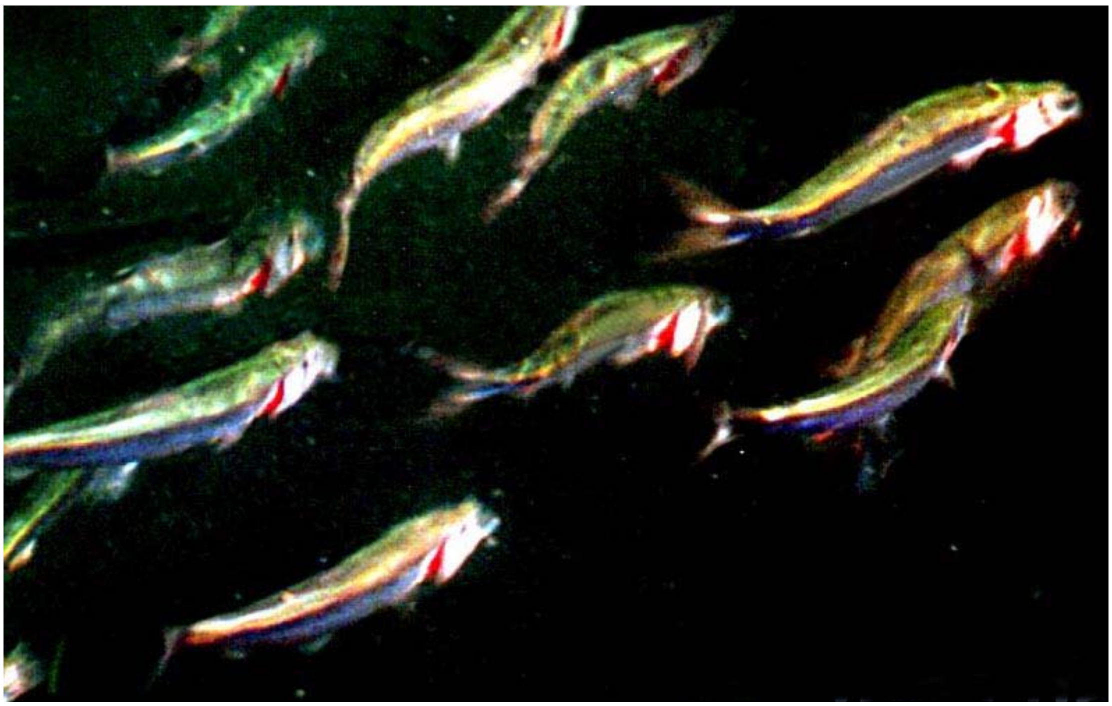
Hunting copepods

Copepods are a group of small crustaceans found in ocean and freshwater habitats. Many species are planktonic (drifting in the ocean water), while others are benthic (living on the sea floor). Copepods are typically one millimetre (0.04 in) to two millimetres (0.08 in) long, with a teardrop shaped body. Like other crustaceans they have an armoured exoskeleton, but they are so small that this armour, and the entire body, is usually transparent.

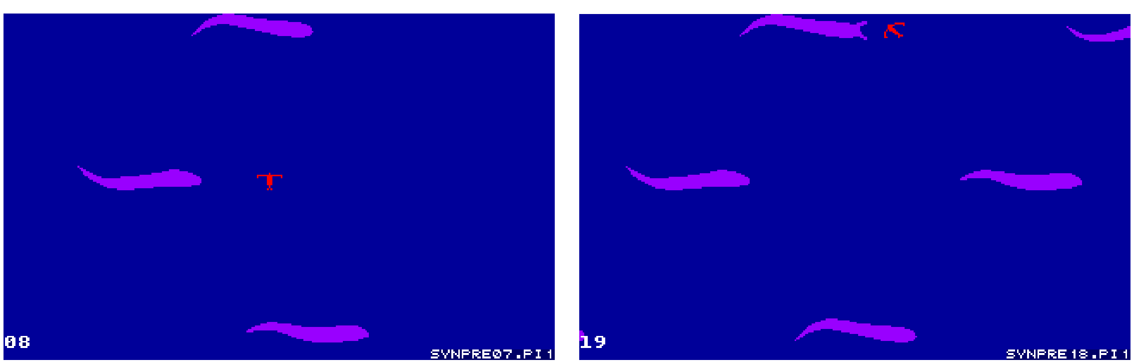
Copepods are usually the dominant zooplankton. Some scientists say they form the largest animal biomass on the planet. The other contender is the Antarctic krill. But copepods are smaller than krill, with faster growth rates, and they are more evenly distributed throughout the oceans. This means copepods almost certainly contribute more secondary production to the world's oceans than krill, and perhaps more than all other groups of marine organisms together. They are a major item on the forage fish menu.

Copepods are very alert and evasive. They have large antennae. When they spread their antennae they can sense the pressure wave from an approaching fish and jump with great speed over a few centimeters.

Herrings are pelagic feeders. Their prey consists of a wide spectrum of phytoplankton and zooplankton, amongst which copepods are the dominant prey. Young herring usually capture small copepods by hunting them individually— they approach them from below. The (half speed) video loop at the left shows a juvenile herring feeding on copepods. In the middle of the image a copepod escapes successfully to the left. The opercula (hard bony flaps covering the gills) are spread wide open to compensate the pressure wave which would alert the copepod to trigger a jump.



Herring ram feeding on a school of copepods.

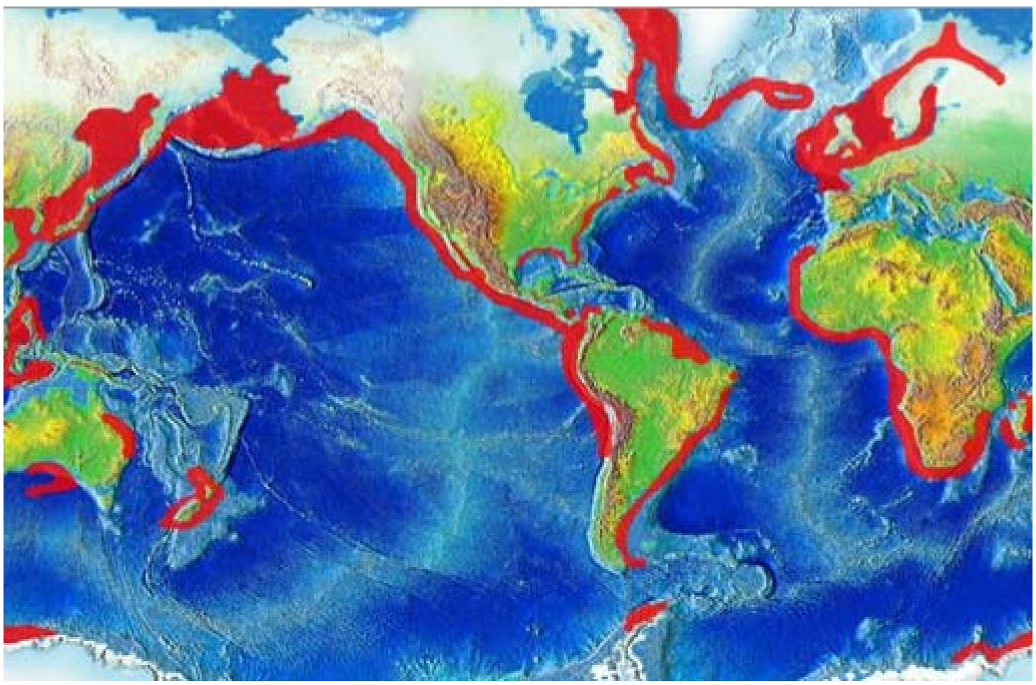


Juvenile herring hunt for the very alert and evasive copepods in synchronization.

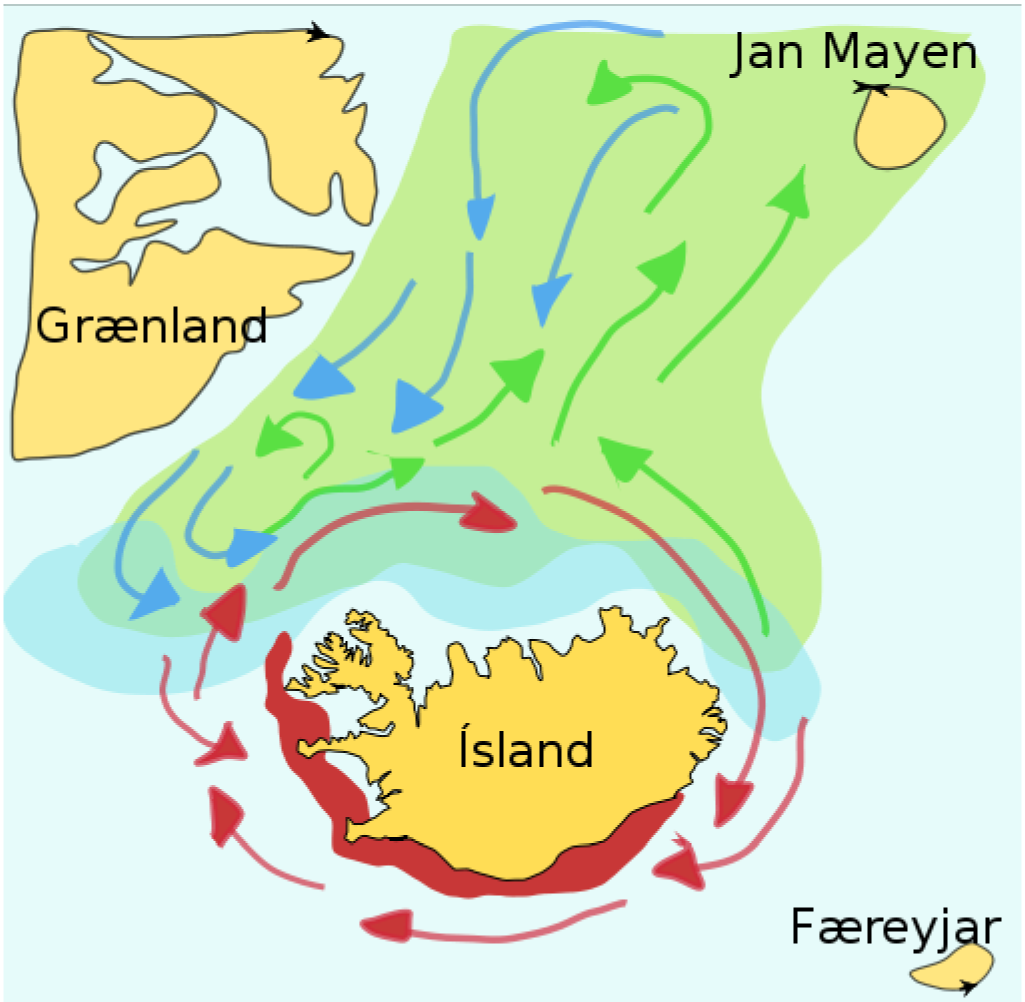
If prey concentrations reach very high levels, the herrings adopt a method called "ram feeding". They swim with their mouth wide open and their opercula fully expanded. Every several feet, they close and clean their gill rakers for a few milliseconds (filter feeding). In the photo on the right, herring ram feed on a school of copepods. The fish all open their mouths and opercula wide at the same time. The fish swim in a grid where the distance between them is the same as the jump length of their prey.

In the image, juvenile herring hunt the copepods in synchronization: The copepods sense with their antennae the pressure-wave of an approaching herring and react with a fast escape jump. The length of the jump is fairly constant. The fish align themselves in a grid with this characteristic jump length. A copepod can dart about 80 times before it tires out. After a jump, it takes it 60 milliseconds to spread its antennae again, and this time delay becomes its undoing, as the almost endless stream of herrings allows a herring to eventually snap the copepod. A single juvenile herring could never catch a large copepod.

Migrations



Coastal upwellings can provide plankton rich feeding grounds for forage fish.



Migration of Icelandic capelin

Forage fish often make great migrations between their spawning, feeding and nursery grounds. Schools of a particular stock usually travel in a triangle between these grounds. For example, one stock of herrings have their spawning ground in southern Norway, their feeding ground in Iceland, and their nursery ground in northern Norway. Wide triangular journeys such as these may be important because forage fish, when feeding, cannot distinguish their own offspring.

Fertile feeding grounds for forage fish are provided by ocean upwellings. Oceanic gyres are large-scale ocean currents caused by the Coriolis effect. Wind-driven surface currents interact with these gyres and the underwater topography, such as seamounts and the edge of continental shelves, to produce downwellings and upwellings. These can transport nutrients which plankton thrive on. The result can be rich feeding grounds attractive to the plankton feeding forage fish. In turn, the forage fish themselves become a feeding ground for larger predator fish. Most upwellings are coastal, and many of them support some of the most productive fisheries in the world. Regions of notable upwelling include coastal Peru, Chile, Arabian Sea, western South Africa, eastern New Zealand and the California coast.

Capelin are a forage fish of the smelt family found in the Atlantic and Arctic oceans. In summer, they graze on dense swarms of plankton at the edge of the ice shelf. Larger capelin also eat krill and other crustaceans. The capelin move inshore in large schools to spawn and migrate in spring and summer to feed in plankton rich areas between Iceland, Greenland, and Jan Mayen. The migration is affected by ocean currents. Around Iceland maturing capelin make large northward feeding migrations in spring and summer. The return migration takes place in September to November. The spawning migration starts north of Iceland in December or January.

The diagram on the right shows the main spawning grounds and larval drift routes. Capelin on the way to feeding grounds is coloured green, capelin on the way back is blue, and the breeding grounds are red. In a paper published in 2009, researchers from Iceland recount their application of an interacting particle model to the capelin stock around Iceland, successfully predicting the spawning migration route for 2008.

Predator attacks

Schooling forage fish are subject to constant attacks by predators. An example is the attacks that take place during the African sardine run. The African sardine run is a spectacular migration by millions of silvery sardines along the southern coastline of Africa. In terms of biomass, the sardine run could rival East Africa's great wildebeest migration.

Gannet

Sardines have a short life-cycle, living only two or three years. Adult sardines, about two years old, mass on the Agulhas Bank where they spawn during spring and summer, releasing tens of thousands of eggs into the water. The adult sardines then make their way in hundreds of shoals towards the sub-tropical waters of the Indian Ocean. A larger shoal might be 7 kilometers (4 mi) long, 1.5 kilometers (1 mi) wide and 30 meters (100 ft) deep. Huge numbers of sharks, dolphins, tuna, sailfish, Cape fur seals and even killer whales congregate and follow the shoals, creating a feeding frenzy along the coastline.

When threatened, sardines instinctively group together and create massive "bait balls". Bait balls can be up to 20 meters (70 ft) in diameter. They are short lived, seldom lasting longer than 20 minutes. As many as 18,000 dolphins, behaving like sheepdogs, round the sardines into these bait balls, or herd them to shallow water (corralling) where they are easier to catch. Once rounded up, the dolphins and other predators take turns plowing through the bait balls, gorging on the fish as they sweep through. Seabirds also attack them from above, flocks of gannets, cormorants, terns and gulls. Some of these seabirds plummet from heights of 30 metres (100 feet), plunging through the water leaving vapour-like trails behind like fighter planes.

The eggs, left behind at the Agulhas Banks, drift northwest with the current into waters off the west coast, where the larvae develop into juvenile fish. When they are old enough, they aggregate into dense shoals and migrate southwards, returning to the Agulhas banks in order to restart the cycle.

Forage fisheries

History

Medieval herring fishing in Scania (published 1555).

Herring has been known as a staple food source since 3000 B.C. In Roman times, anchovies were the base for the fermented fish sauce called *garum.* This staple of cuisine was produced in industrial quantities and transported over long distances.

Fishing for sardela or sardina (*Sardina pilchardus*) is an ongoing activity on the Croatian Adriatic coasts of Dalmatia and Istria. It traces its roots back thousands of years. The region was then largely a Venetian dominion, part of the Roman Empire. The area has always been sustained through fishing mainly sardines. Along the coast towns still promote the traditional practice of fishing by lateen sail boats for tourism and festivals.

Pilchard fishing and processing thrived in Cornwall between 1750 and 1880, after which stocks went into an almost terminal decline. Recently (2007) stocks have been improving. The industry has featured in many works of art, including Stanhope Forbes and other Newlyn School artists.

Contemporary

Traditional commercial fisheries were directed towards high value ocean predators such as cod, rockfish and tuna, rather than humble forage fish. As technologies developed, fisheries became so effective at locating and catching predator fish that many of the stocks collapsed. The industry compensated by turning to species lower in the food chain.

In former times, forage fish were more difficult to fish profitably, and were a small part of the global marine fisheries. But modern industrial fishing technologies have enabled the removal of increasing quantities. Industrial-scale forage fish fisheries need large scale landings of fish to return profits. They are dominated by a small number of corporate fishing and processing companies.

Purse seine boats encircling a school of menhaden

Forage fish populations are very vulnerable when faced with modern fishing equipment. They swim near the surface in compacted schools, so they are relatively easy to locate at the surface with sophisticated electronic fishfinders and from above with spotter planes. Once located, they are scooped out of the water using highly efficient nets, such as purse seines, which remove most of the school.

Spawning patterns in forage fish are highly predictable. Some fisheries use knowledge of these patterns to harvest the forage species as they come together to spawn, removing the fish before they have actually spawned. Fishing during spawning periods or at other times when forage fish amass in large numbers can also be a blow to predators. Many predators, such as whales, tuna and sharks, have evolved to migrate long distances to specific sites for feeding and breeding. Their survival hinges on their finding these forage schools at their feeding grounds. The great ocean predators find that, no matter how they are adapted for speed, size, endurance or stealth, they are on the losing side when faced with the machinery of contemporary industrial fishing.

Commercial herring catch

Altogether, forage fish account for 37 percent (31.5 million tonnes) of all fish taken from the world's oceans each year. However, because there are fewer species of forage fish compared to predator fish, forage species fisheries are the largest in the world. Seven of the top ten fisheries target forage fish. The total world catch of herrings, sardines and anchovies alone in 2005 was 22.4 million tonnes, 24 percent of the total world catch.

The Peruvian anchoveta fishery is now the biggest in the world (10.7 million tonnes in 2004), while the Alaskan pollock fishery in the Bering Sea is the largest single species fishery in the world (3 million tonnes). The Alaskan pollock is said to be the largest remaining single species source of palatable fish in the world. However, the biomass of pollock has declined in recent years, perhaps spelling trouble for both the Bering Sea ecosystem and the commercial fishery it supports. Acoustic surveys by NOAA indicate that the 2008 pollock population is almost 50 percent lower than last year's survey levels. Some scientists think this decline in Alaska pollock could repeat the collapse experienced by Atlantic cod, which could have negative consequences for the entire Bering Sea ecosystem. Salmon, halibut, endangered Steller sea lions, fur seals, and humpback whales eat pollock and depend on healthy populations to sustain themselves.

Use as animal feed

Eighty percent of the forage fish caught are feed to animals. Ninety percent is processed into fishmeal and fish oil. Of this, 46 percent was feed to farmed fish, 24 percent to pigs, and 22 percent to poultry (2002). Six times the weight of forage fish is feed to pigs and poultry alone than the entire seafood consumption of the U.S. market.

According to Turchini and De Silva (2008), another 2.5 million tonnes of the annual forage fish catch is consumed by the global cat food industry. In Australia, pet cats eat 13.7 kilograms of fish a year compared to the 11 kilograms eaten by the average Australian. The pet food industry is increasingly marketing premium and super-premium products, when different raw materials, such as the by-products of the fish filleting industry, could be used instead.

Environmental issues

A recent study (2008) by fisheries scientists Jacqueline Alder, Daniel Pauly and colleagues is the product of a nine-year Sea Around Us Project. The study concludes that...

“

1. The composition of landings of forage fish fisheries have changed over the past 50 years with the trophic level of fish used in fishmeal increasing over the past 20 years.
2. Our understanding of the role of forage fish in marine ecosystem and the impact of fishing is still limited.
3. Landing of forage fish peaked by the 1970s, and these high levels are highly unlikely in the future, even if fisheries are managed sustainably.
4. The consumption of forage fish by seabirds and marine mammals is not likely to be onerous to fisheries, except in a few localized areas. By contrast, fisheries, by reducing the biomass of small pelagics, might pose a threat to these predators, particularly to those species for which stocks have been heavily depleted by human exploitation in the past.
5. Some forage fish species are consumed by many people with consumption patterns changing over the last 20 years.
6. Aquaculture continues to increase its consumption of fishmeal and fish oil.

”

In lakes and rivers

Forage fish also inhabit freshwater habitats, such as lakes and rivers, where they serve as food for larger freshwater predators. Usually smaller than 15 centimetres (6 in) in length, these small bait fish make up most of the fish found in lakes and rivers. The minnow family alone, consisting of minnows, chubs, shiners and daces, consists of more than fifty species. Other freshwater forage fish include suckers, killifish, shad, bony fish as well as fish of the sunfish family, excluding black basses and crappie, and smaller species of the carp family. There are also anadromous forage fish, such as eulachon.

Freshwater forage fish

Killifish

Southern redbelly dace

Chinese minnow

Swarm of carp

Twaite shad

Within any fresh or saltwater ecosystem, there will always be both desirable and undesirable fishes, and this varies from country to country, and often from region to region within a country. Sport fishermen divide freshwater predators of forage fish into those:

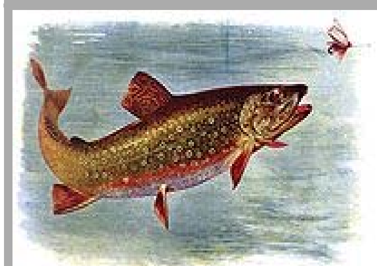
- which have a good fighting ability and are good to eat, called sport (or game) fish.
- the other less desirable fish, called rough fish in North America and coarse fish in Britain

Rough or coarse fish usually refers to fish that are not commonly eaten, not sought after for sporting reasons, or have become invasive species reducing the populations of desirable fish. They compete for forage fish with the more popular sport fish. They are often regarded as a nuisance, and are not usually protected by game laws. Forage fish generally are not considered rough or coarse fish because of their usefulness as bait.

The term *rough fish* is used by U.S. state agencies and anglers to describe undesirable predator fish. In North America, anglers fish for salmon, trout, bass, pike, catfish, walleye and muskellunge. The smallest fish are called panfish, because they can fit in a standard cooking pan. Some examples are crappies, rock bass, perch, bluegill and sunfish.

The term *coarse fish* originated in the United Kingdom in the early 19th century. Prior to that time, recreational fishing was the sport of the gentry, who angled for trout and salmon which they called "game fish". Fish other than game fish were disdained as "coarse fish". These days, "game fish" refers to Salmonids (other than grayling) — that is, salmon, trout and char. Coarse fish are made up mostly of the larger species of Cyprinids (carp, roach, bream) as well as pike, catfish, gar and lamprey. Coarse fish are no longer disdained; indeed, fishing for coarse fish has become a popular pastime.

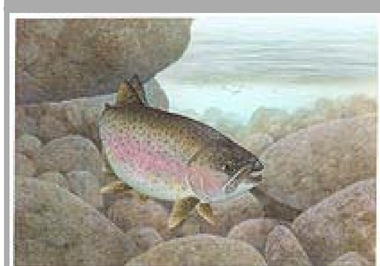
Freshwater predators of forage fish



Brook trout

Black crappie

Macquarie perch



Rainbow trout

Pink salmon

Channel catfish

Bait and feeder fish

Forage fish are sometimes referred to as *bait fish* or *feeder fish*. Bait fish is a term used particularly by recreational fishermen, although commercial fisherman also catch fish to bait longlines and traps. Forage fish is a fisheries term, and is used in the context of fisheries. Bait fish, by contrast, are fish that are caught by humans to use as bait for other fish. The terms overlap in the sense that most bait fish are also forage fish, and vice versa. Feeder fish is a term used particularly in the context of fish aquariums. It refers essentially to the same concept as forage fish, small fish that are eaten by larger fish, but the term is adapted to the particular requirements of working with fish in aquariums.

Timeline

- 2006: The U.S. National Coalition for Marine Conservation asks U.S. fishery managers to put "Forage First!". Their campaign was launched with the publication of their report, *Taking the Bait: Are America's Fisheries Out-*

competing Predators for their Prey?, available at cost to the U. S. fishing industry, encouraging fishery managers to protect predator-prey relationships as a first step toward an ecosystem based approach to fishery management.

- 2009: The international Lenfest Forage Fish Task Force is established to develop workable management plans for tackling the depletion of forage fish.

Chapter- 9

Pelagic Fish

A school of large pelagic predator fish (giant trevally) sizing up a school of small pelagic fish (anchovies)

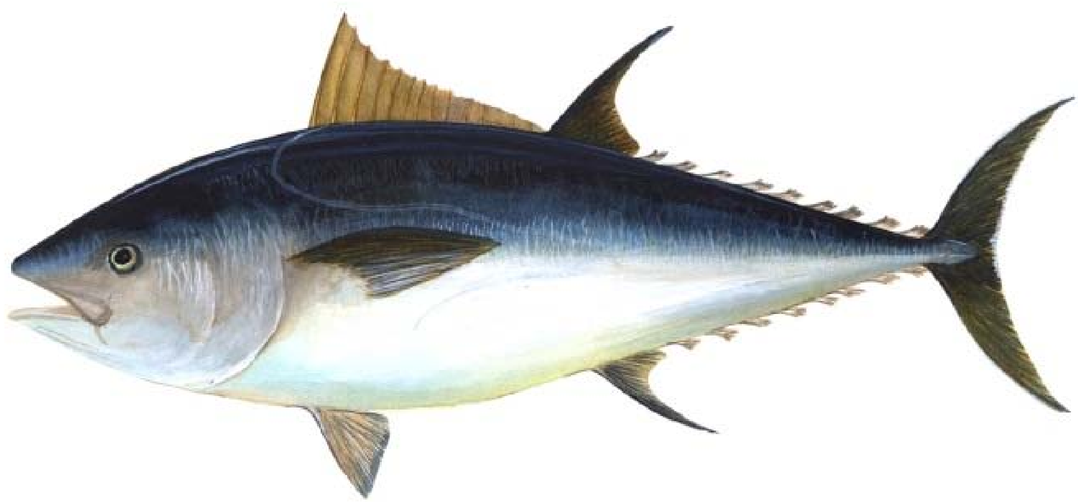
Pelagic fish live in the water column of coastal, ocean and lake waters, but not on the bottom of the sea or the lake. They can be contrasted with demersal fish, which do live on or near the bottom, and reef fish which are associated with coral reefs.

The marine pelagic environment is the largest aquatic habitat on earth, occupying 1,370 million cubic kilometres (330 million cubic miles), and is the habitat for 11 percent of known fish species. The oceans have a mean depth of 4000 meters. About 98 percent of the total water volume is below 100 meters, and 75 percent is below 1000 metres.

Marine pelagic fish can be divided into coastal (inshore) fish and oceanic (offshore) fish. Coastal fish inhabit the relatively shallow and sunlit waters above the continental shelf, while oceanic fish (which may well also swim inshore) inhabit the vast and deep waters beyond the continental shelf.

Pelagic fish range in size from small coastal forage fish, such as herrings and sardines, to large apex predator oceanic fishes, such as the Southern bluefin tuna and oceanic sharks. They are usually agile swimmers with streamlined bodies, capable of sustained cruising on long distance migrations. The Indo-Pacific sailfish, an oceanic pelagic fish, can sprint at over 110 kilometres per hour. Some tuna species cruise across the Pacific Ocean. Many pelagic fish swim in schools weighing hundreds of tonnes. Others are solitary, like the large ocean sunfish weighing over 500 kilograms, which sometimes drift passively with ocean currents, eating jellyfish.

Epipelagic fish



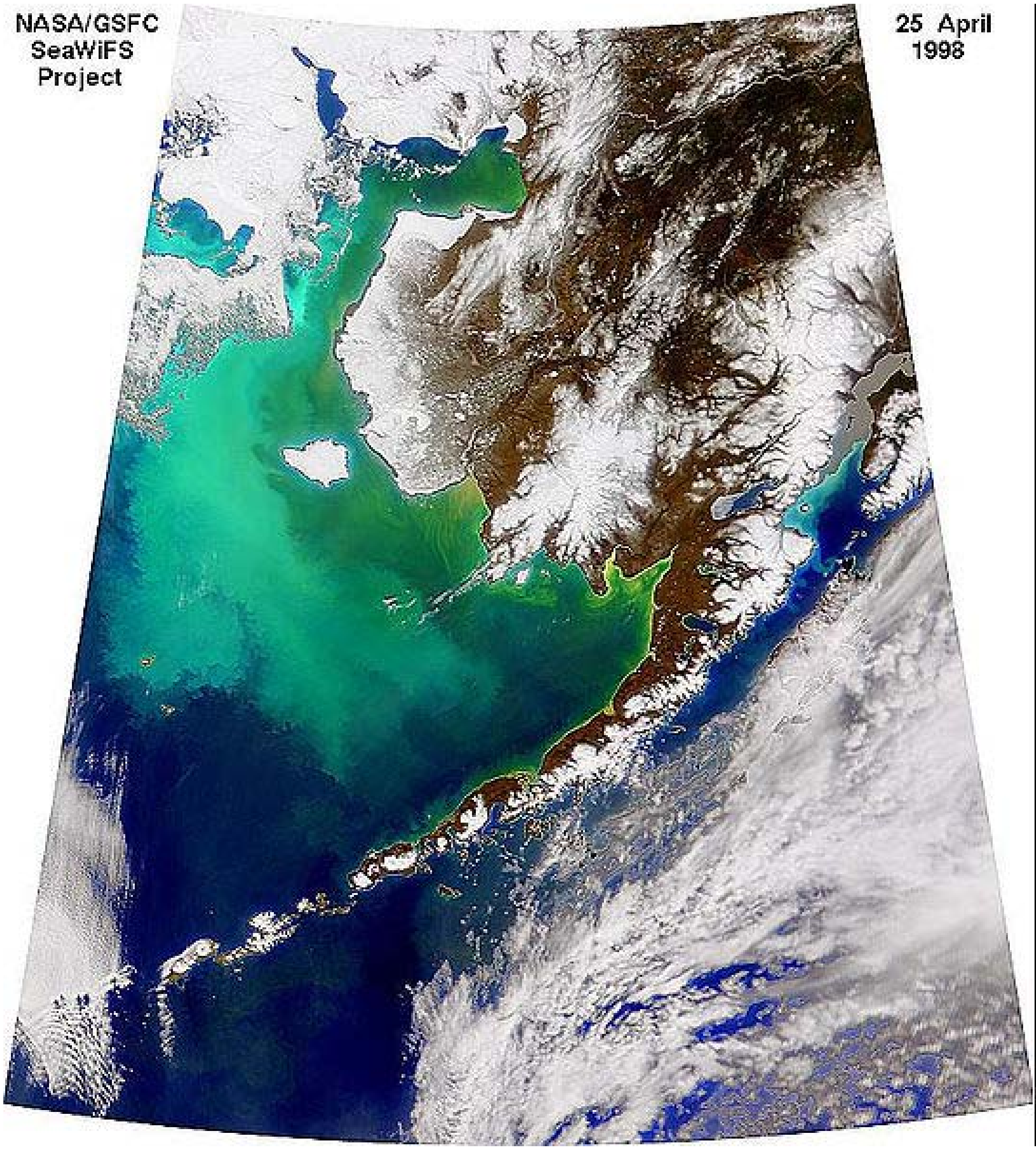
Large epipelagic predator fish, like this Northern bluefin tuna, have a deeply forked tail and a smooth body shaped like a spindle tapered at both ends and countershaded with silvery colours.

Small epipelagic forage fish, like this Atlantic herring, share the same body features listed for the predator fish above

Epipelagic fish inhabit the epipelagic zone. The epipelagic zone is the water from the surface of the sea down to 200 metres. It is also referred to as the **surface waters** or the **sunlit zone**, and includes the photic zone. The photic zone is defined as the surface waters down to the point where the sunlight has attenuated to 1 percent of the surface value. This depth depends on how turbid the water is, but in clear water can extend to 200 metres, coinciding with the epipelagic zone. The photic zone has sufficient light for phytoplankton to photosynthese.

The epipelagic zone is vast, and is the home for most pelagic fish. The zone is well lit so visual predators can use their eye sight, is usually well mixed and oxygenated from wave action, and can be a good habitat for algae to grow. However, it is an almost featureless habitat. This lack of habitat diversity results in a lack of species diversity, so the zone supports less than 2 percent of the world's known fish species. Much of the zone lacks nutrients for supporting fish, so epipelagic fish tend to be found in coastal water above the continental shelves, where land runoff can provide nutrients, or in those parts of the ocean where upwelling moves nutrients into the area.

Epipelagic fish can be broadly divided into small forage fish and larger predator fish which feed on them. Forage fish school and filter feed on plankton. Most epipelagic fish have streamlined bodies capable of sustained cruising on migrations. In general, predatory and forage fish share the same morphological features. Predator fish are usually fusiform with large mouths, smooth bodies, and deeply forked tails. Many use vision to predate zooplankton or smaller fish, while others filter feed on plankton. Both predators and their smaller prey are usually countershaded with silvery colours which reduce visibility by scattering incoming light.



Satellite image of a large coccolithophore bloom in the Bering Sea in 1998

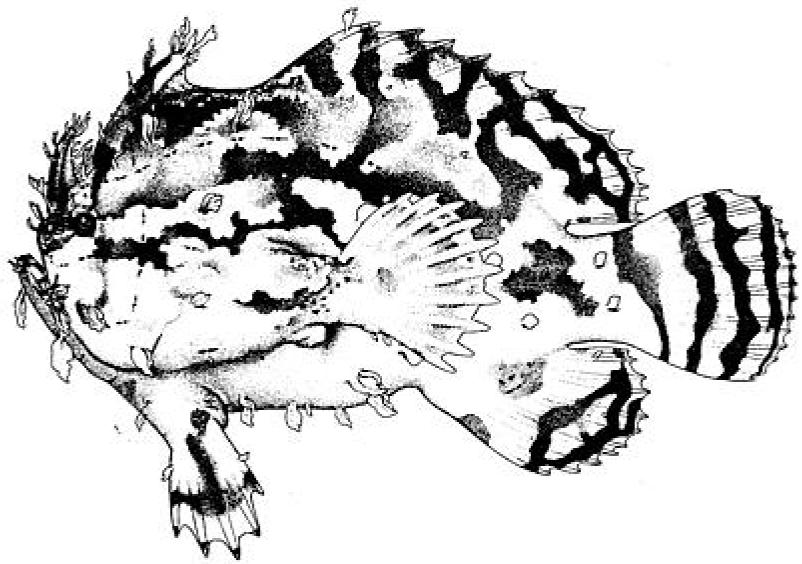
Though the number of species is limited, epipelagic fishes are abundant. What they lack in diversity they make up in numbers. Forage fish occur in huge numbers, and large fish that predate on them are often sought after as premier food fish. As a group, epipelagic fishes form the most valuable fisheries in the world.

Many forage fish are facultative predators that can pick individual copepods or fish larvae out of the water column, and then change to filter feeding on phytoplankton when energetically that gives better results. Filter feeding fish usually use long fine gill rakers to strain small organisms from the water column. Some of the largest epipelagic fishes, such as the basking shark and whale shark are filter feeders, and so are some of the smallest, such as adult sprats and anchovies.

Ocean waters that are exceptionally clear contain little food. Areas of high productivity tend to be somewhat turbid from plankton blooms. These attract the filter feeding plankton eaters, which in turn attract the higher predators. Tuna fishing tends to be optimum when water turbidity, measured by the maximum depth a secchi disc can be seen during a sunny day, is 15 to 35 metres.

Floating objects

Drifting *Sargassum* seaweed provides food and shelter for small epipelagic fish

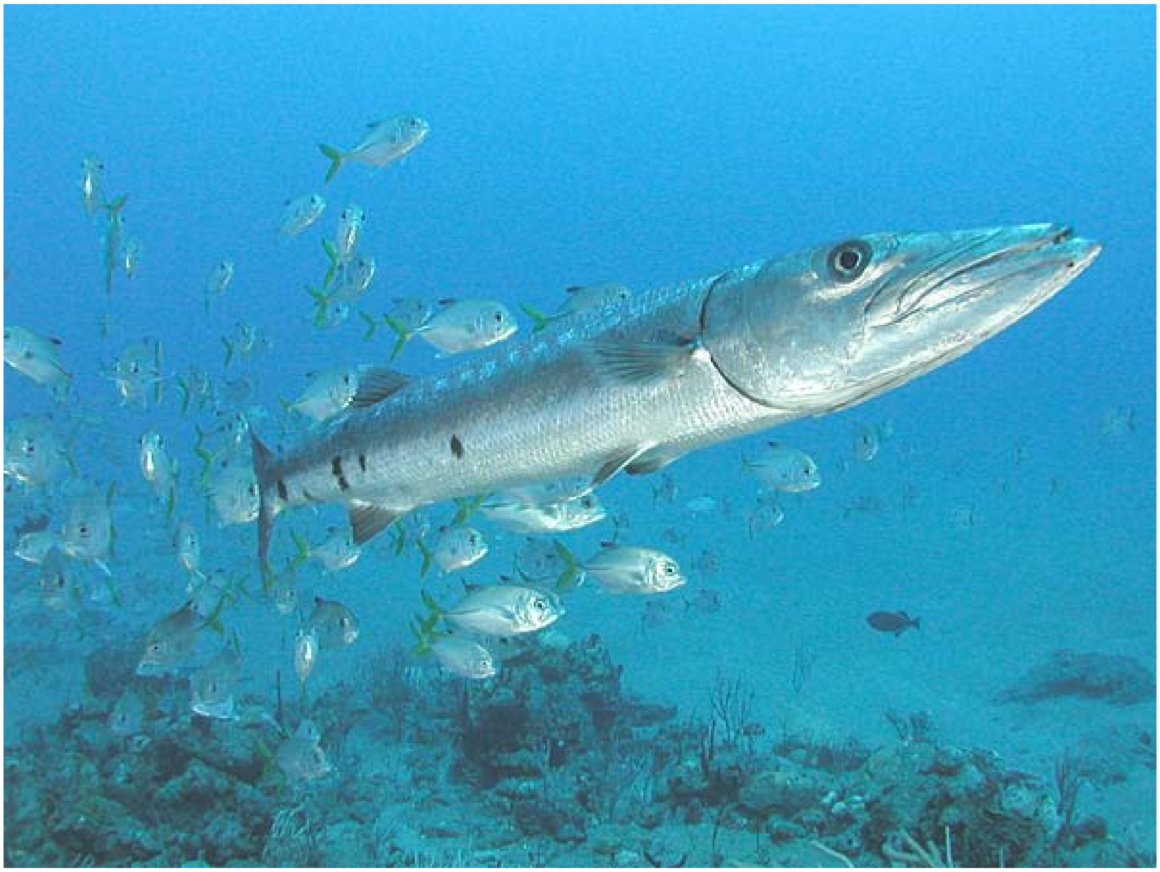


The endemic sargassum fish has evolved to live among drifting *Sargassum* seaweed

Epipelagic fish are fascinated with floating objects. They aggregate in considerable numbers around objects such as drifting flotsam, rafts, jellyfish and floating seaweed. The objects appear to provide a "visual stimulus in an optical void". Floating objects can offer some protection for juvenile fish from predators. The availability of lots of drifting seaweed or jellyfish can result in significant increases in the survival rates of some juvenile species.

Many coastal juveniles use seaweed for the shelter and the food that is available from invertebrates and other fish associated with it. Drifting seaweed, particularly the pelagic Sargassum, provide a niche habitat with its own shelter and food, and even supports its own unique fauna, such as the sargassum fish. One study, off Florida, found 54 species from 23 families living in flotsam from *Sargassum* mats. Jellyfish are also used by juvenile fish for shelter and food, even though jellyfish may prey on small fish.

Mobile oceanic species such as tuna can be captured by travelling long distances in large fishing vessels. A simpler alternative is to leverage off the fascination fish have with floating objects. When fishermen use such objects, they are called fish aggregating devices (FADs). FADs are anchored rafts or objects of any type, floating on the surface or just below it. Fishermen in the Pacific and Indian oceans set up floating FADs, assembled from all sorts of debris, around tropical islands, and then use purse seines to capture the fish attracted to them.

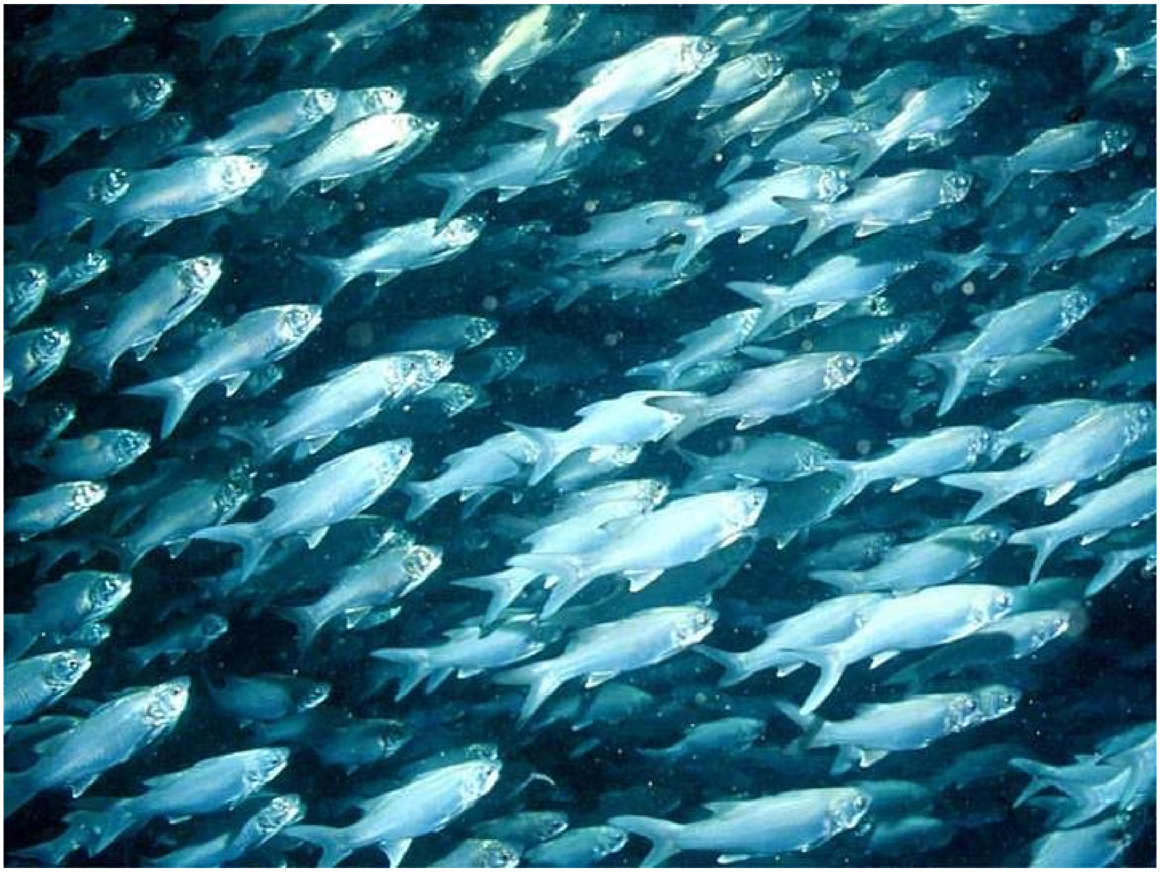


Great barracuda accompanied by a school of jacks

A study using sonar in French Polynesia, found large shoals of juvenile bigeye tuna and yellowfin tuna aggregated closest to the devices, 10 to 50m. Further out, 50 to 150m, was a less dense group of larger yellowfin and albacore tuna. Yet further out, to 500m, was a dispersed group of various large adult tuna. The distribution and density of these groups was variable end overlapped. The FADs were also used by other fish, and the aggregations dispersed when it was dark.

Larger fish, even predator fish, such as the great barracuda in the photo on the left, often attract a retinue of small fish that accompany them in a strategically safe way. Skindivers who remain for long periods in the water, also often attract a retinue of fish, with smaller fishes coming in close, and larger fishes observing from a greater distance. Marine turtles, functioning as a mobile shelter for small fish, can be impaled accidentally by a swordfish trying to catch the fish.

Coastal fish

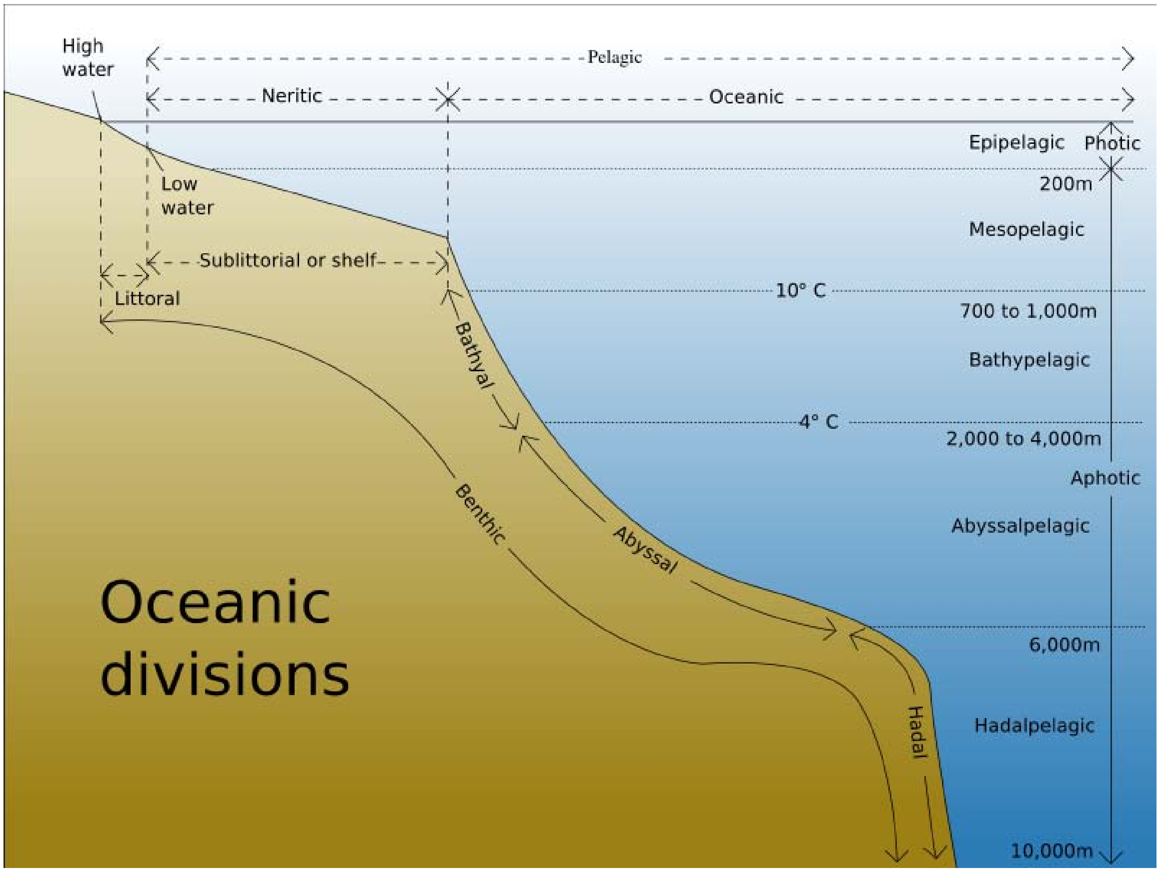


Schooling threadfin, a coastal species

Coastal fish (also called neritic or inshore fish) inhabit the waters near the coast and above the continental shelf. Since the continental shelf is usually less than 200 metres deep, it follows that coastal fish that are not demersal fish are usually epipelagic fish, inhabiting the sunlit epipelagic zone.

Coastal epipelagic fish are among the most abundant in the world. They include forage fish as well as the predator fish that feed on them. Forage fish thrive in those inshore waters where high productivity results from the upwelling and shoreline run off of nutrients. Some are partial residents that spawn in streams, estuaries and bays, but most complete their life cycle in the zone.

Oceanic fish



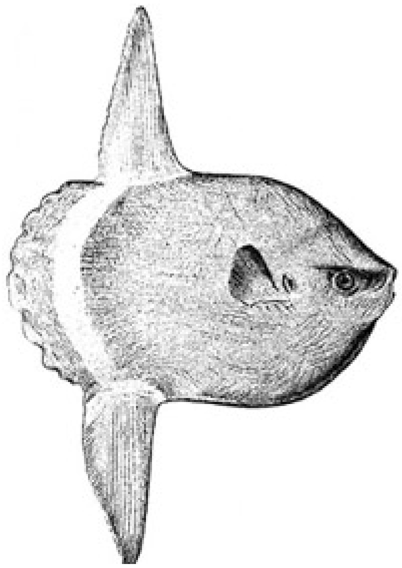
Oceanic fish inhabit the oceanic zone, which is the deep open water which lies beyond the continental shelves.

Oceanic fish (also called open ocean or offshore fish) live in the waters that are not above the continental shelf. Oceanic fish can be contrasted with coastal fish, who do live above the continental shelf. However, the two types are not mutually exclusive, since there are no firm boundaries between coastal and ocean regions, and many epipelagic fish move between coastal and oceanic waters, particularly in different stages in their life cycle.

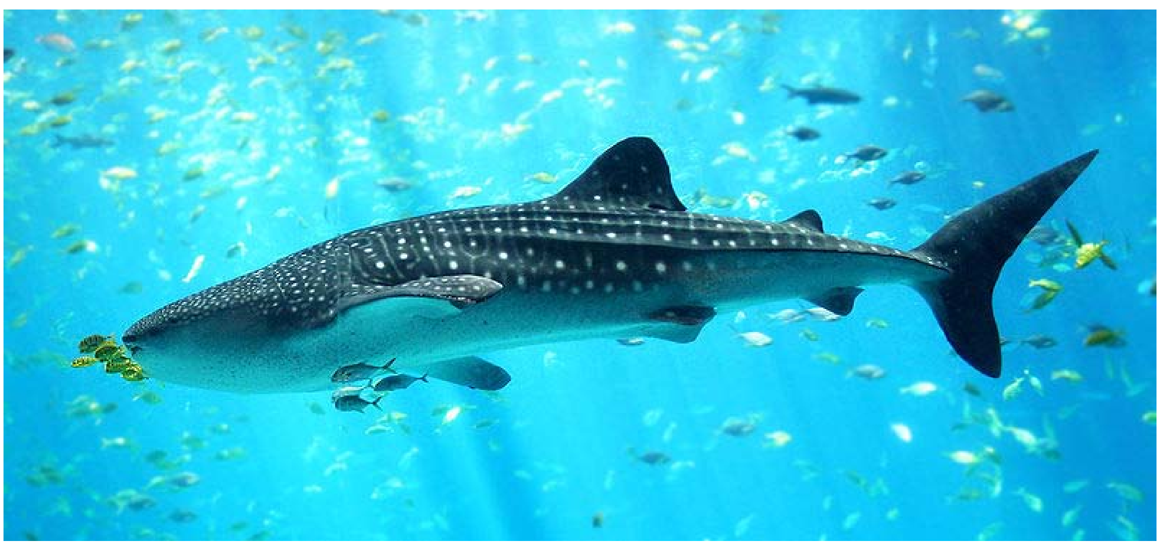
Oceanic epipelagic fish can be true residents, partial residents, or accidental residents. True residents live their entire life in the open ocean. Only a few species are true residents, such as tuna, billfish, flying fish, sauries, commercial pilotfish and remoras, dolphin, ocean sharks and ocean sunfish. Most of these species migrate back and forth across open oceans, rarely venturing over continental shelves. Some true residents associate with drifting jellyfish or seaweeds.

Partial residents occur in three groups: species which live in the zone only when they are juveniles (drifting with jellyfish and seaweeds); species which live in the zone only when they are adults (salmon, flying fish, dolphin and whale sharks); and deep water species which make nightly migrations up into the surface waters (such as the lanternfish).

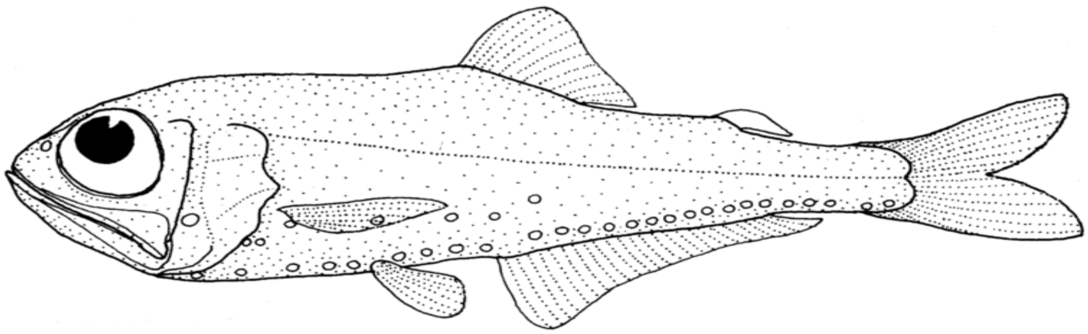
Accidental residents occur occasionally when adults and juveniles of species from other environments are carried by accident into the zone by currents.



The huge ocean sunfish, a true resident of the ocean epipelagic zone, sometimes drifts with the current, eating jellyfish

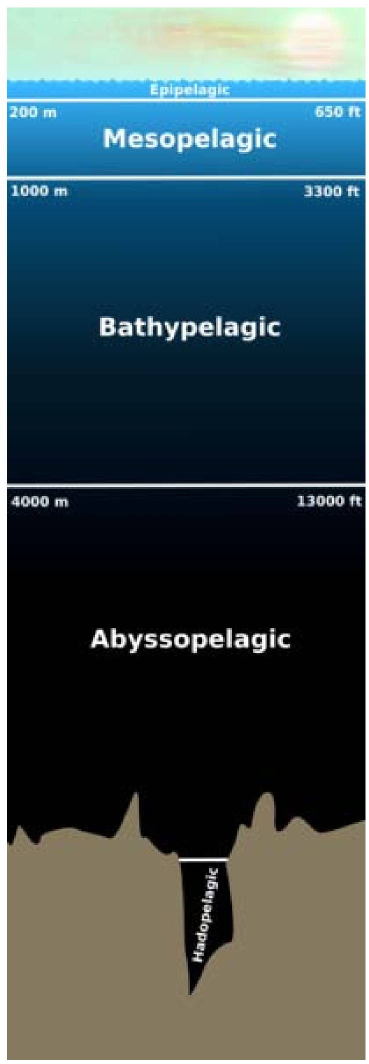


The giant whale shark, another resident of the ocean epipelagic zone, filter feeds on plankton, and periodically dives deep into the mesopelagic zone.



Lanternfish are partial residents of the ocean epipelagic zone. During the day they hide in deep waters, but at night they migrate up to surface waters to feed.

Deep-water fish



Scale diagram of the layers of the pelagic zone

In the deep ocean, the waters extend far below the epipelagic zone, and support very different types of pelagic fishes adapted to living in these deeper zones.

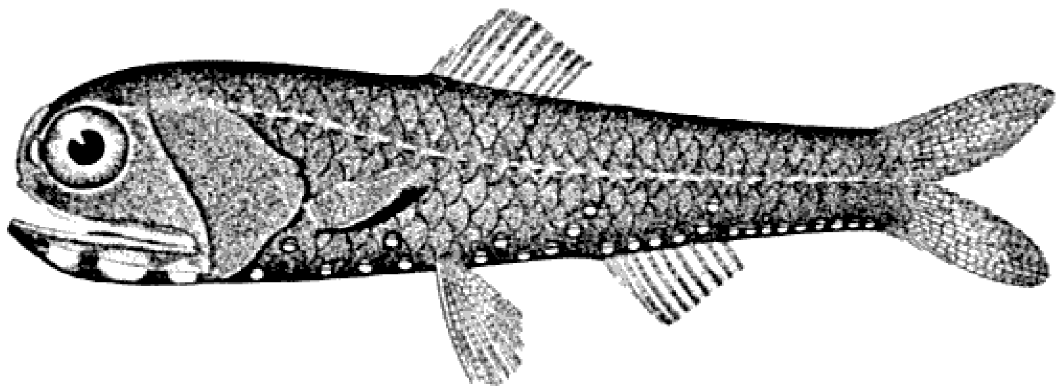
In deep water, marine snow is a continuous shower of mostly organic detritus falling from the upper layers of the water column. Its origin lies in activities within the productive photic zone. Marine snow includes dead or dying plankton), protists (diatoms), fecal matter, sand, soot and other inorganic dust. The "snowflakes" grow over time and may reach several centimetres in diameter, travelling for weeks before reaching the ocean floor. However, most organic components of marine snow are consumed by microbes, zooplankton and other filter-feeding animals within the first 1,000 metres of their journey, that is, within the epipelagic zone. In this way marine snow may be considered the foundation of deep-sea mesopelagic and benthic ecosystems: As sunlight cannot reach them, deep-sea organisms rely heavily on marine snow as an energy source.

Some deep-sea pelagic groups, such as the lanternfish, ridgehead, marine hatchetfish, and lightfish families are sometimes termed *pseudoceanic* because, rather than having an even distribution in open water, they occur in significantly higher abundances around structural oases, notably seamounts and over continental slopes. The phenomenon is explained by the likewise abundance of prey species which are also attracted to the structures.

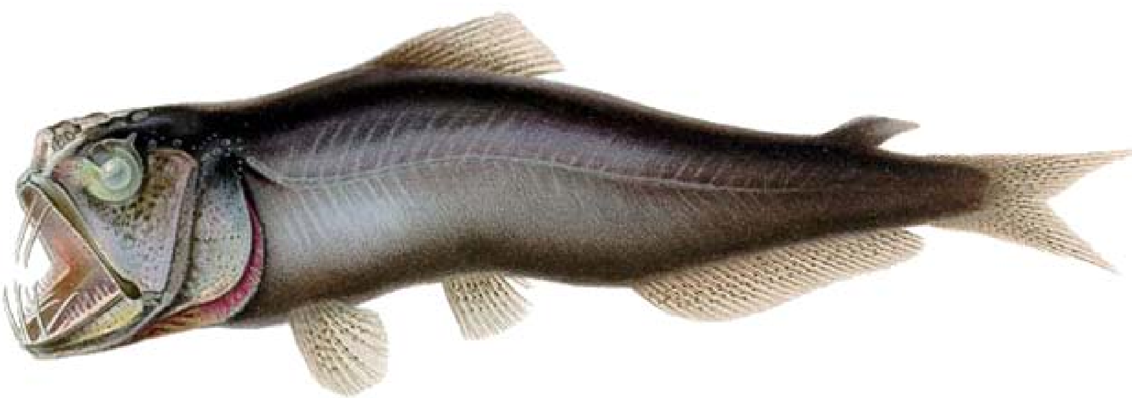
The fish in the different pelagic and deep water benthic zones are physically structured, and behave in ways, that differ markedly from each other. Groups of coexisting species within each zone all seem to operate in similar ways, such as the small mesopelagic vertically migrating plankton-feeders, the bathypelagic anglerfishes, and the deep water benthic rattails. "

Ray finned species, with spiny fins, are rare among deep sea fishes, which suggests that deep sea fish are ancient and so well adapted to their environment that invasions by more modern fishes have been unsuccessful. The few ray fins that do exist are mainly in the Beryciformes and Lampriformes, which are also ancient forms. Most deep sea pelagic fishes belong to their own orders, suggesting a long evolution in deep sea environments. In contrast, deep water benthic species, are in orders that include many related shallow water fishes.

Mesopelagic fish



Most mesopelagic fishes are small filter feeders which ascend at night to feed in the nutrient rich waters of the epipelagic zone. During the day, they return to the dark, cold, oxygen deficient waters of the mesopelagic where they are relatively safe from predators. Lanternfish account for as much as 65 percent of all deep sea fish biomass and are largely responsible for the deep scattering layer of the world's oceans.



Most of the rest of the mesopelagic fishes are ambush predators, like this sabertooth fish. The sabertooth which uses its telescopic, upward-pointing eyes to pick out prey silhouetted against the gloom above. Their recurved teeth prevent a captured fish from backing out.

Below the epipelagic zone, conditions change rapidly. Between 200 metres and about 1000 metres, light continues to fade until there is almost none. Temperatures fall through a thermocline to temperatures between 39°F and 46°F. This is the **twilight** or mesopelagic zone. Pressure continues to increase, at the rate of one atmosphere every 10 metres, while nutrient concentrations fall, along with dissolved oxygen and the rate at which the water circulates."

Sonar operators, using the newly developed sonar technology during World War II, were puzzled by what appeared to be a false sea floor 300–500 metres deep at day, and less deep at night. This turned out to be due to millions of marine organisms, most particularly small mesopelagic fish, with swimbladders that reflected the sonar. These organisms migrate up into shallower water at dusk to feed on plankton. The layer is deeper when the moon is out, and can become shallower when clouds pass over the moon. This phenomenon has come to be known as the deep scattering layer.

Most mesopelagic fish make daily vertical migrations, moving at night into the epipelagic zone, often following similar migrations of zooplankton, and returning to the depths for safety during the day. These vertical migrations often occur over a large vertical distances, and are undertaken with the assistance of a swimbladder. The swimbladder is inflated when the fish wants to move up, and, given the high pressures in the messoplegic zone, this requires significant energy. As the fish ascends, the pressure in the swimbladder must adjust to prevent it from bursting. When the fish wants to return to the depths, the swimbladder is deflated. Some mesopelagic fishes make daily migrations through the thermocline, where the temperature changes between 10 and 20 °C, thus displaying considerable tolerances for temperature change.

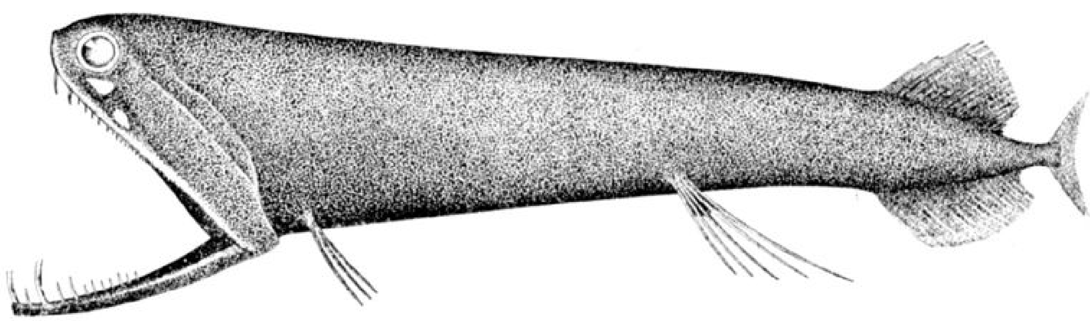
These fish have muscular bodies, ossified bones, scales, well developed gills and central nervous systems, and large hearts and kidneys. Mesopelagic plankton feeders have small mouths with fine gill rakers, while the piscivores have larger mouths and coarser gill rakers. The vertically migratory fish have swimbladders.

Mesopelagic fish are adapted for an active life under low light conditions. Most of them are visual predators with large eyes. Some of the deeper water fish have tubular eyes with big lenses and only rod cells that look upwards. These give binocular vision and great sensitivity to small light signals. This adaptation gives improved terminal vision at the expense of lateral vision, and allows the predator to pick out squid, cuttlefish, and smaller fish that are silhouetted against the gloom above them.

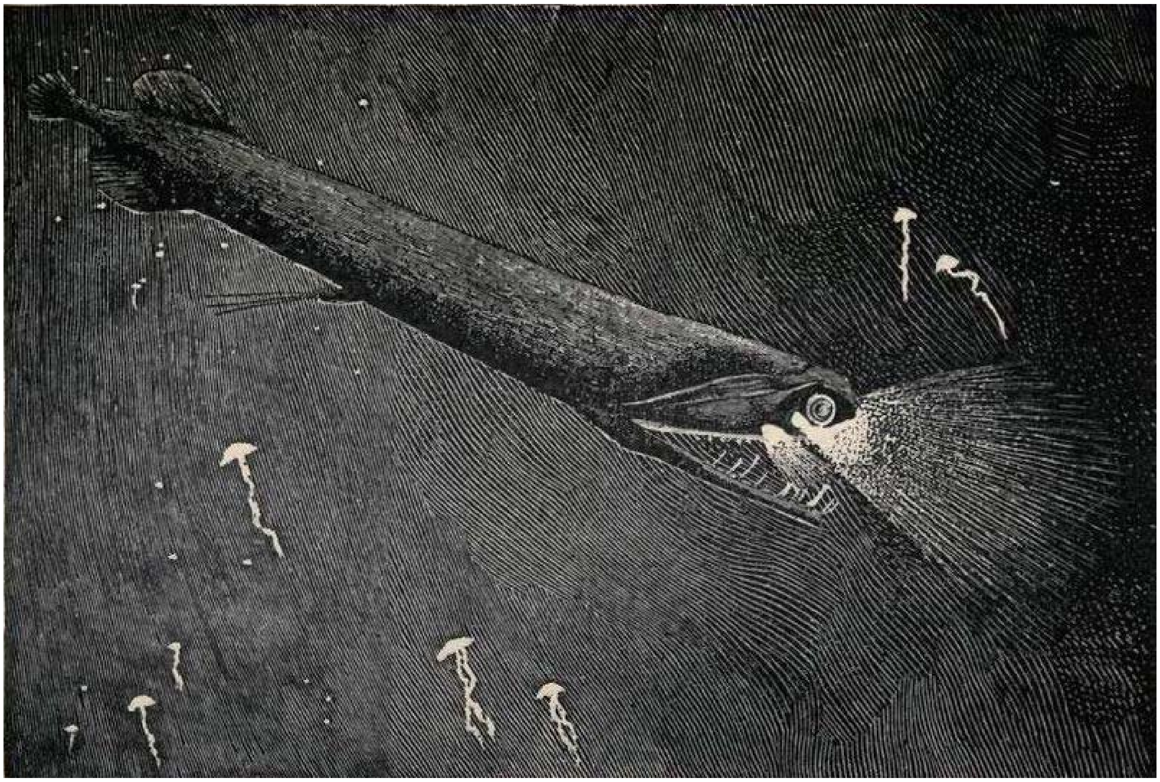
Mesopelagic fish usually lack defensive spines, and use colour to camouflage them from other fish. Ambush predators are dark, black or red. Since the longer, red, wavelengths of light do not reach the deep sea, red effectively functions the same as black. Migratory forms use countershaded silvery colours. On their bellies, they often display photophores producing low grade light. For a predator from below, looking upwards, this bioluminescence camouflages the silhouette of the fish. However, some of these predators have yellow lenses that filter the (red deficient) ambient light, leaving the bioluminescence visible

The Antarctic toothfish have large, upward looking eyes, adapted to detecting the silhouettes of prey fish.

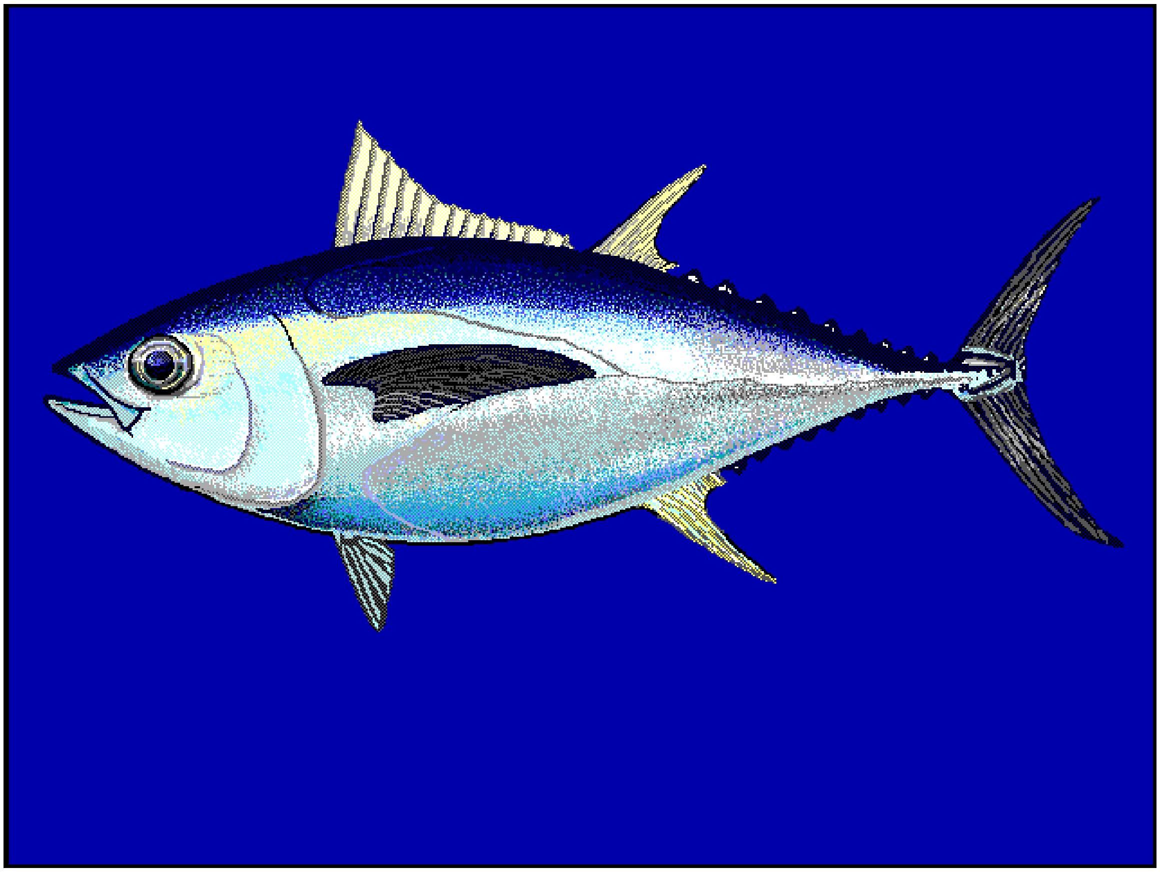
The Barreleye has barrel-shaped, tubular eyes which are generally directed upwards but can be swivelled forward.



The stoplight loosejaw has a lower jaw one-quarter as long as its body. The jaw has no floor and is attached only by a hinge and a modified tongue bone. Large fang-like teeth in the front are followed by many small barbed teeth.



The stoplight loosejaw is also one of the few fishes that produce red bioluminescence. As most of their prey cannot perceive red light, this allows it to hunt with an essentially invisible beam of light.

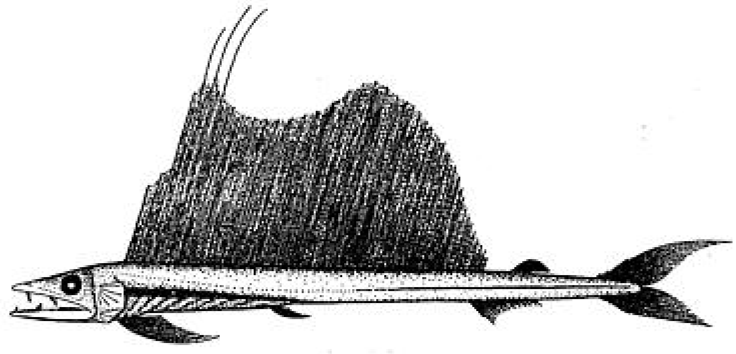


Bigeye tuna cruise the epipelagic zone at night and the mesopelagic zone during the day.

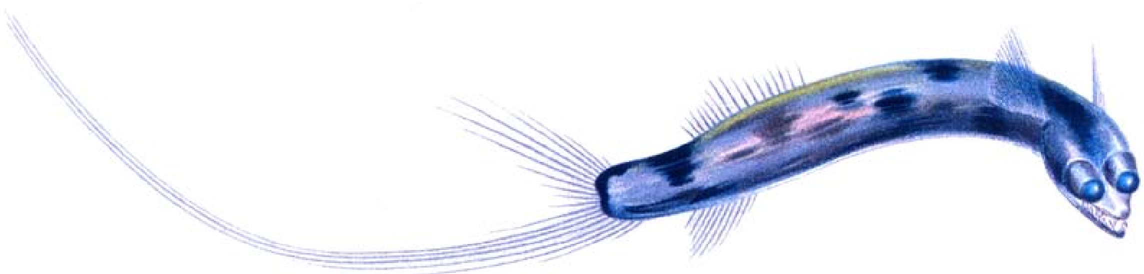
The brownsnout spookfish is a species of barreleye is the only vertebrate known to employ a mirror, as opposed to a lens, to focus an image in its eyes.

Sampling via deep trawling indicates that lanternfish account for as much as 65% of all deep sea fish biomass. Indeed, lanternfish are among the most widely distributed, populous, and diverse of all vertebrates, playing an important ecological role as prey for larger organisms. The estimated global biomass of lanternfish is 550 - 660 million metric tonnes, several times the entire world fisheries catch. Lanternfish also account for much of the biomass responsible for the deep scattering layer of the world's oceans. Sonar reflects off the millions of lanternfish swim bladders, giving the appearance of a false bottom.

Bigeye tuna are an epipelagic/mesopelagic species that eats other fish. Satellite tagging has shown that bigeye tuna often spend prolonged periods cruising deep below the surface during the daytime, sometimes making dives as deep as 500 metres. These movements are thought to be in response to the vertical migrations of prey organisms in the deep scattering layer.



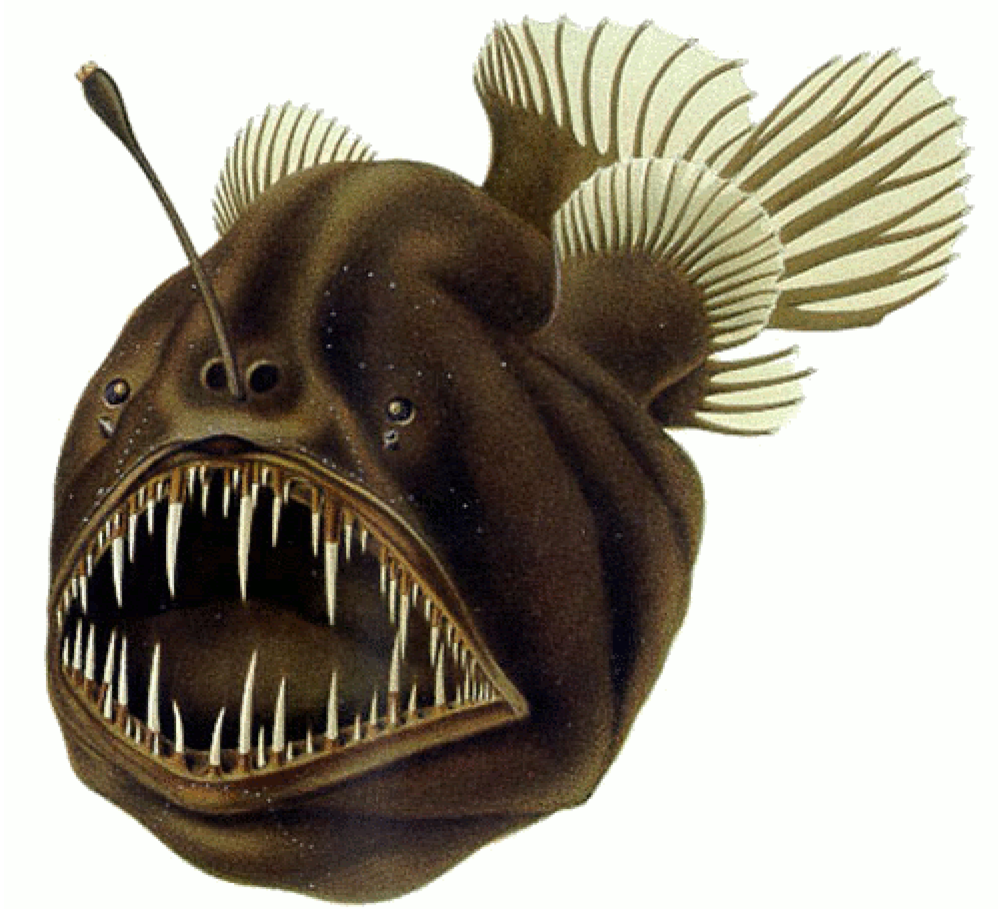
Longnose lancetfish. Lancetfish are ambush predators which spend all their time in the mesopelagic zone. They are among the largest mesopelagic fishes (up to 2 metres).



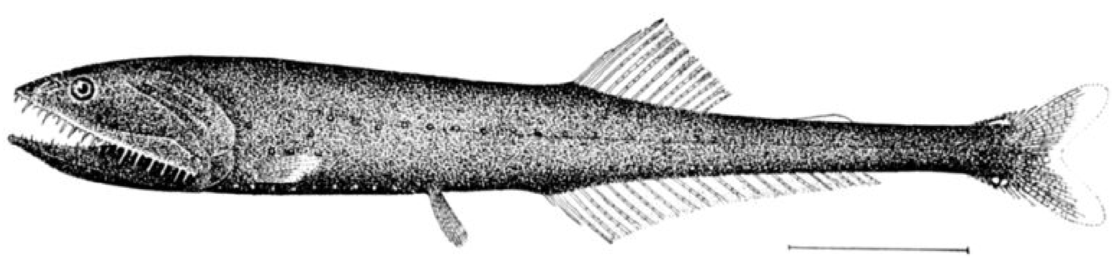
The telescopefish has large, forward-pointing telescoping eyes with large lenses.

The daggertooth paralyses other mesopelagic fish when it bites them with its dagger-like teeth.

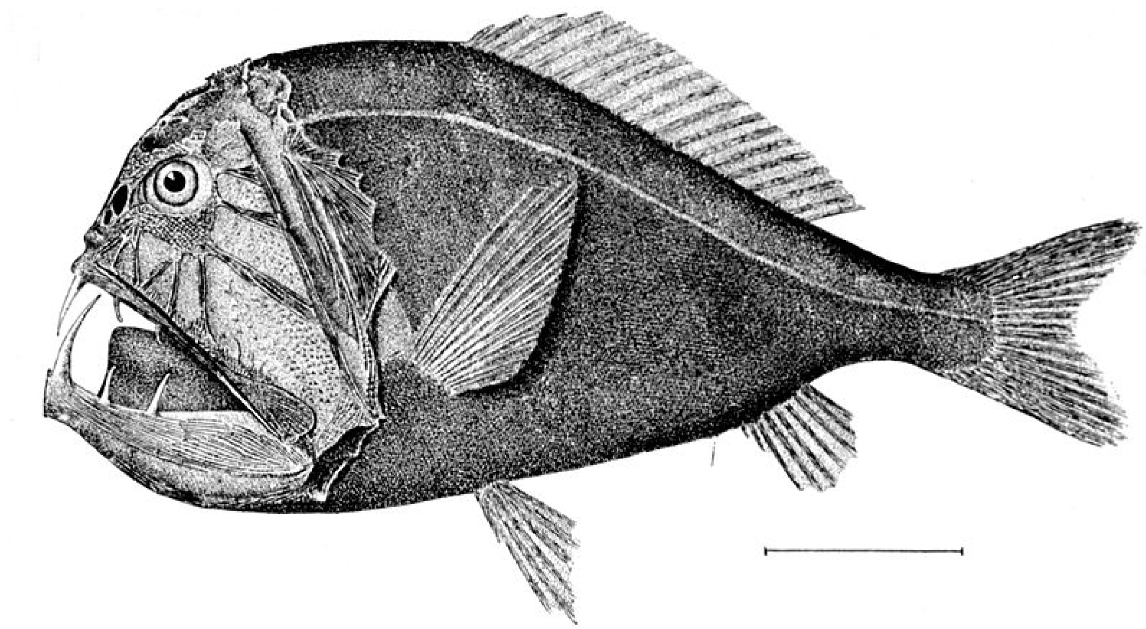
Bathypelagic fish



The humpback anglerfish is a bathypelagic ambush predators, which attract prey with a bioluminescent lure. It can ingest prey larger than itself, which it swallows with an inrush of water when it opens its mouth.



Many bristlemouth species, such as the "spark anglemouth" above, are also bathypelagic ambush predators which can swallow prey larger than themselves. They are among the most abundant of all vertebrate families.



The widespread fangtooth has the largest teeth of any fish, proportionate to body size. Despite their ferocious appearance, bathypelagic fish are usually weakly muscled and too small to represent any threat to humans.

Below the mesopelagic zone it is pitch dark. This is the **midnight** or bathypelagic zone, extending from 1000 metres to the bottom deep water benthic zone. If the water is exceptionally deep, the pelagic zone below 4000 metres is sometimes called the **lower midnight** or abyssopelagic zone.

Conditions are somewhat uniform throughout these zones, the darkness is complete, the pressure is crushing, and temperatures, nutrients and dissolved oxygen levels are all low.

Bathypelagic fish have special adaptations to cope with these conditions – they have slow metabolisms and unspecialized diets, being willing to eat anything that comes along. They prefer to sit and wait for food rather than waste energy searching for it. The behaviour of bathypelagic fish can be contrasted with the behaviour of mesopelagic fish. Mesopelagic are often highly mobile, whereas bathypelagic fish are almost all lie-in-wait predators, normally expending little energy in movement.

The dominant bathypelagic fishes are small bristlemouth and anglerfish; fangtooth, viperfish, daggertooth and barracudina are also common. These fishes are small, many about 10 centimetres long, and not many longer than 25 cm. They spend most of their time waiting patiently in the water column for prey to appear or to be lured by their phosphors. What little energy is available in the bathypelagic zone filters from above in the form of detritus, faecal material, and the occasional invertebrate or mesopelagic fish.

About 20 percent of the food that has its origins in the epipelagic zone falls down to the mesopelagic zone, but only about 5 percent filters down to the bathypelagic zone.

Bathypelagic fish are sedentary, adapted to outputting minimum energy in a habitat with very little food or available energy, not even sunlight, only bioluminescence. Their bodies are elongated with weak, watery muscles and skeletal structures. Since so much of the fish is water, they are not compressed by the great pressures at these depths. They often have extensible, hinged jaws with recurved teeth. They are slimy, without scales. The central nervous system is confined to the lateral line and olfactory systems, the eyes are small and may not function, and gills, kidneys and hearts, and swimbladders are small or missing.

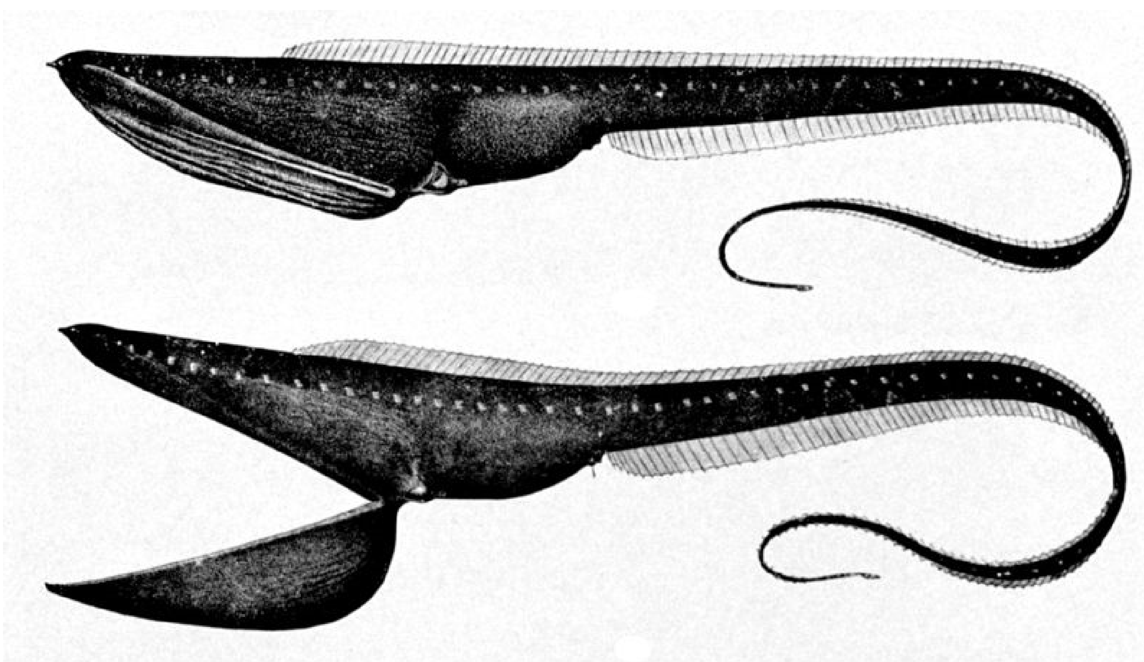
These are the same features found in fish larvae, which suggests that during their evolution, bathypelagic fish have acquired these features through neoteny. As with larvae, these features allow the fish to remain suspended in the water with little expenditure of energy.

Despite their ferocious appearance, these beasts of the deep are mostly miniature fish with weak muscles, and are too small to represent any threat to humans.

The swimbladders of deep sea fish are either absent or scarcely operational, and bathypelagic fish do not normally undertake vertical migrations. Filling bladders at such great pressures incurs huge energy costs. Some deep sea fishes have swimbladders which function while they are young and inhabit the upper epipelagic zone, but they wither or fill with fat when the fish move down to their adult habitat.

The most important sensory systems are usually the inner ear, which responds to sound, and the lateral line, which responds to changes in water pressure. The olfactory system can also be important for males who find females by smell.

Flashlight fish have a retroreflector behind the retina which they use with photophores to detect eyeshine in other fish.



The gulper eel uses its mouth like a net by opening its large mouth and swimming at its prey. It has a luminescent organ at the tip of its tail to attract prey.

The black swallower, with its distensible stomach, is notable for its ability to swallow, whole, bony fishes ten times its mass.

Young, red flabby whalefish make nightly vertical migrations into the lower mesopelagic zone to feed on copepods. When males make the transition to adults, they develop a massive liver, and then their jaws fuse shut. They eat no longer, but continue to metabolise the energy stored in their liver.

The Sloane's viperfish can make nightly migrations from bathypelagic depths to near surface waters.

Bathypelagic fish are black, or sometimes red, with few photophores. When photophores are used, it is usually to entice prey or attract a mate. Because food is so scarce, bathypelagic predators are not selective in their feeding habits, but grab whatever come close enough. They accomplish this by having a large mouth with sharp teeth for grabbing large prey and overlapping gill rakers which prevent small prey that have been swallowed from escaping.

It is not easy finding a mate in this zone. Some species depend on bioluminescence. Others are hermaphrodites, which doubles their chances of producing both eggs and sperm when an encounter occurs. The female anglerfish releases pheromones to attract tiny males. When a male finds her, he bites on to her and never lets go. When a male of the anglerfish species *Haplophryne mollis* bites into the skin of a female, he release an enzyme that digests the skin of his mouth and her body, fusing the pair to the point where the two circulatory systems join up. The male then atrophies into nothing more than a pair of gonads. This extreme sexual dimorphism ensures that, when the female is ready to spawn, she has a mate immediately available.

Many forms other than fish live in the bathypelagic zone, such as squid, large whales, octopuses, sponges, brachiopods, sea stars, and echinoids, but this zone is difficult for fish to live in.

Demersal fish

Giant grenadier, an elongate benthic fish with large eyes and well-developed lateral lines

Demersal fish live on or near the bottom of the sea. Demersal fish are found by the seafloor in coastal areas on the continental shelf, and in the open ocean they are found along the outer continental margin on the continental slope and the continental rise. They are not generally found at abyssopelagic or hadopelagic depths or on the abyssal plain. They occupy a range of seafloors consisting of mud, sand, gravel or rocks.

In deep waters, the fishes of the demersal zone, compared to fishes of the bathypelagic zone, are active and relatively abundant."

Rattails and brotulas are common, and other well established families are eels, eelpouts, hagfishes, greeneyes, batfishes and lumpfishes.

The bodies of deep water benthic fishes are muscular with well developed organs. In this way they are closer to mesopleagic fishes than bathopelagic fishes. In other ways, they are more variable. Photophores are usually absent, eyes and swimbladders range from absent to well developed. They vary in size, with larger species greater than one metre not uncommon.

Deep sea benthic fish are usually long and narrow. Many are eels or shaped like eels. This may be because long bodies have long lateral lines. Lateral lines detect low-frequency sounds, and some benthic fishes appear to have muscles that drum such sounds to attract mates. Smell is also important, as indicated by the rapidity with which benthic fish find traps baited with bait fish.

The main diet of deep sea benthic fish is invertebrates of the deep sea benthos and carrion. Smell, touch and lateral line sensitivities seem to be the main sensory devices for locating these.

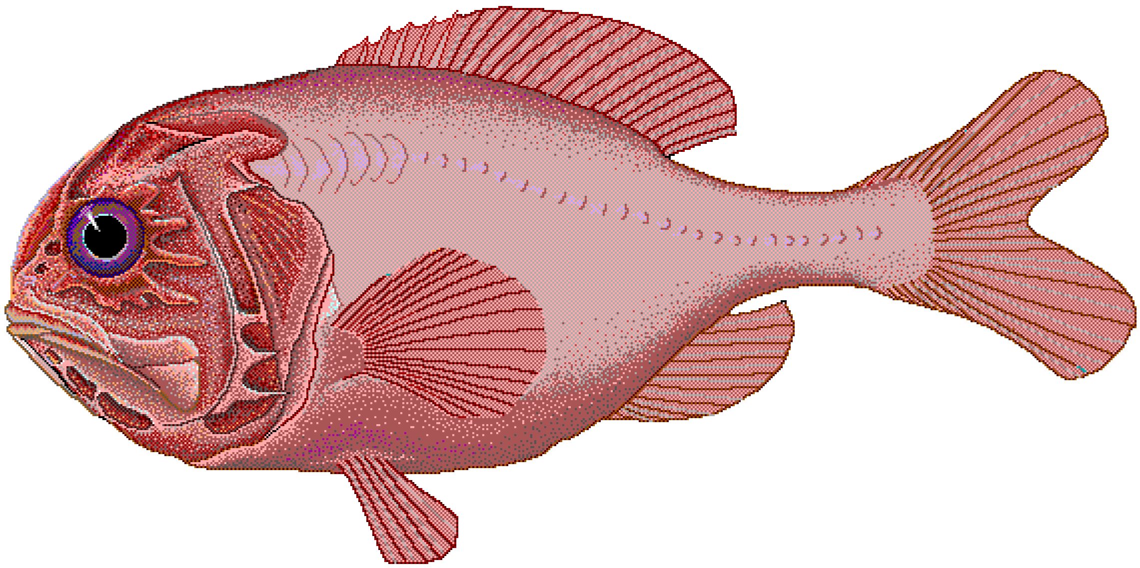
Deep sea benthic fish can be divided into strictly benthic fish and benthopelagic fish. Usually strictly benthic fish are negatively buoyant while benthopelagic fish are neutrally buoyant. Strictly benthic fish stay in constant contact with the bottom. They either lie-and-wait as ambush predators or move actively over the bottom in search for food.

Benthopelagic fish

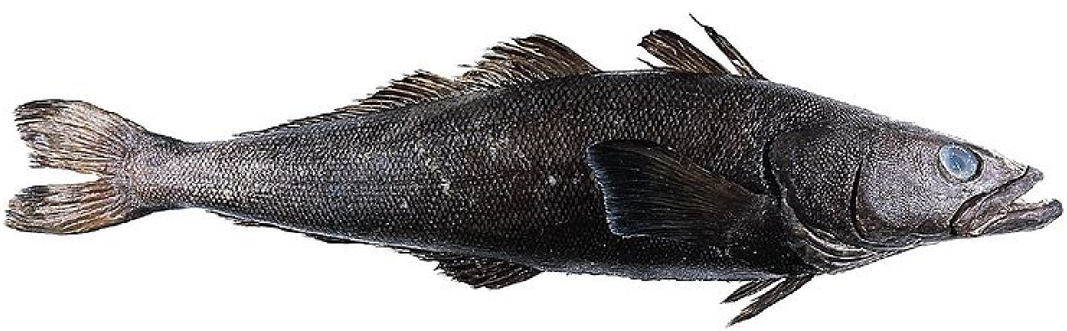
Benthopelagic fish inhabit the water just above the bottom, feeding on benthos and benthopelagic zooplankton. Most dermersal fish are benthopelagic.

They can be divided into flabby or robust body types. Flabby benthopelagic fishes are like bathopelagic fishes, they have a reduced body mass, and low metabolic rates, expending minimal energy as they lie and wait to ambush prey. An example of a flabby fish is the cusk-eel *Acanthonus armatus*, a predator with a huge head and a body that is 90 percent water. This fish has the largest ears (otoliths) and the smallest brain in relation to its body size of all known vertebrates.

Robust benthopelagic fish are muscular swimmers that actively cruise the bottom searching for prey. They may live around features, such as seamounts, which have strong currents. Examples are the orange roughy and Patagonian toothfish. Because these fish were once abundant, and because their robust bodies are good to eat, these fish have been commercially harvested.



Orange roughy



Patagonian toothfish

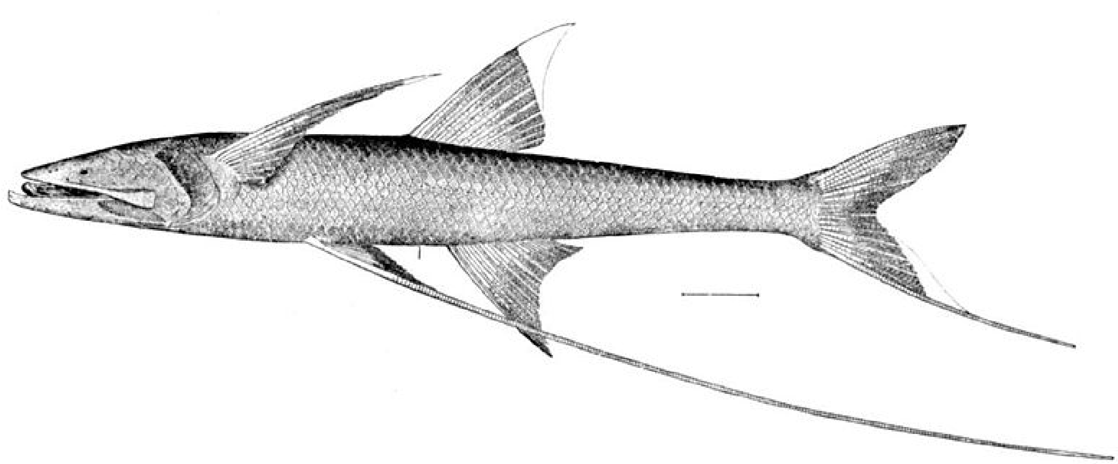
Benthic fish

Benthic fish are not pelagic fish, but they are discussed here briefly, by way of completeness and contrast.

Some fishes don't fit into the above classification. For example, the family of nearly blind spiderfishes, common and widely distributed, feed on benthopelagic zooplankton. Yet they are strictly benthic fish, since they stay in contact with the bottom. Their fins have long rays they use to "stand" on the bottom while they face the current and grab zooplankton as it passes by.

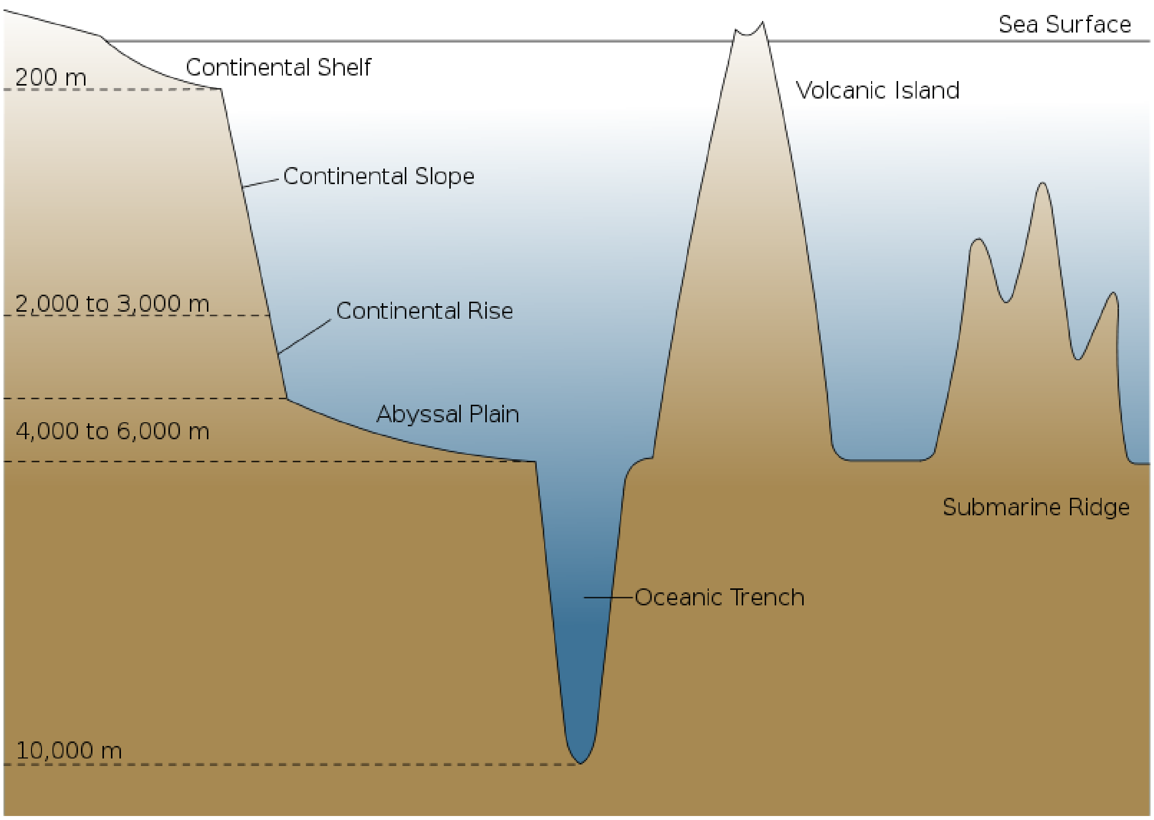
The deepest-living fish known, the strictly benthic *Abyssobrotula galatheae*, eel-like and blind, feeds on benthic invertebrates.

Pacific hagfish resting on bottom. Hagfish coat themselves and any dead fish they find with noxious slime making them inedible to other species."



The tripod fish, a species of spiderfish, uses its fin extensions to "stand" on the bottom.

The blotched fantail ray feeds on bottom-dwelling fish, bivalves, crabs and shrimps.



Cross-section of an ocean basin. Note significant vertical exaggeration.

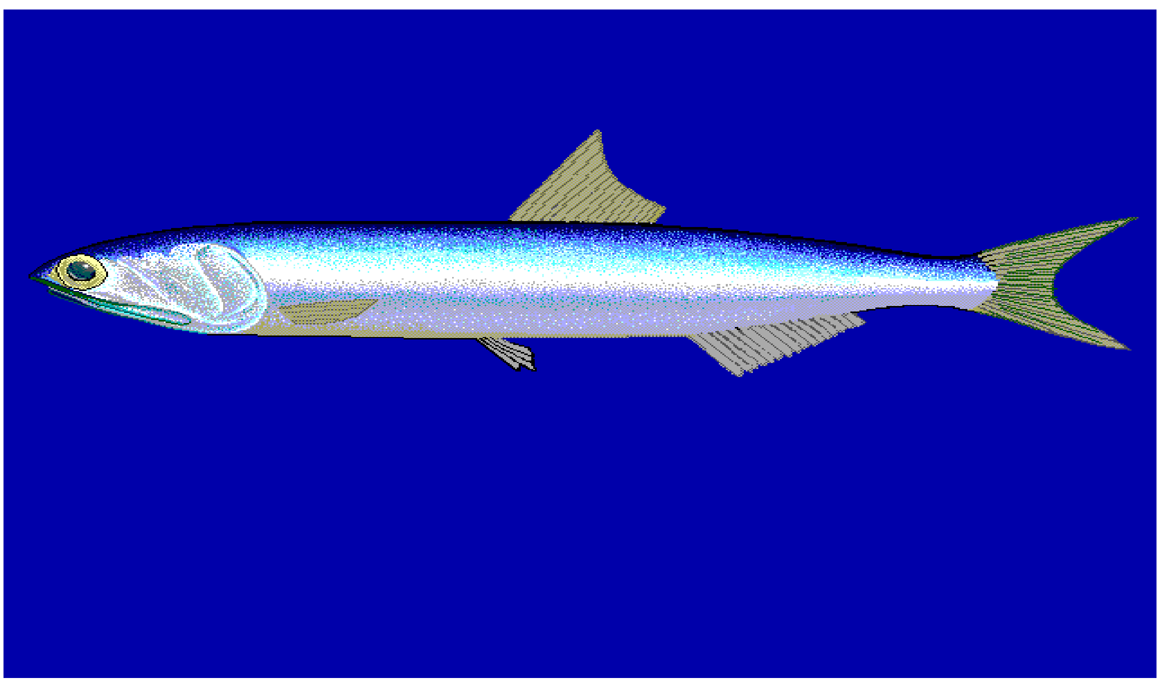
At great depths, food scarcity and extreme pressure works to limit the survivability fish. The deepest point of the ocean is about 11,000 metres. Bathypelagic fishes are not normally found below 3,000 metres. The greatest depth recorded for a benthic fish is 8,370 m. It may be that extreme pressures interfere with essential enzyme functions.

Benthic fishes are likely to be found, and are more diverse, on the continental slope, where there is habitat diversity and often food supplies. About 40% of the ocean floor consists of abyssal plains, but these flat, featureless regions are covered with sediment and largely devoid of benthic life (benthos). Deep sea benthic fishes are more likely to associate with canyons or rock outcroppings among the plains, where invertebrate communities are established. Undersea mountains (seamounts) can intercept deep sea currents, and cause productive upwellings which support benthic fish. Undersea mountain ranges can separate underwater regions into different ecosystems.

Pelagic fisheries

Forage fish

Small pelagic fish are usually forage fish that are hunted by larger pelagic fish and other predators. Forage fish filter feed on plankton and are usually less than 10 centimetres long. They often stay together in schools and may migrate large distances between spawning grounds and feeding grounds. They are found particularly in upwelling regions around the northeast Atlantic, off the coast of Japan, and off the west coasts of Africa and the Americas. Forage fish are generally short-lived, and their stocks fluctuate markedly over the years.



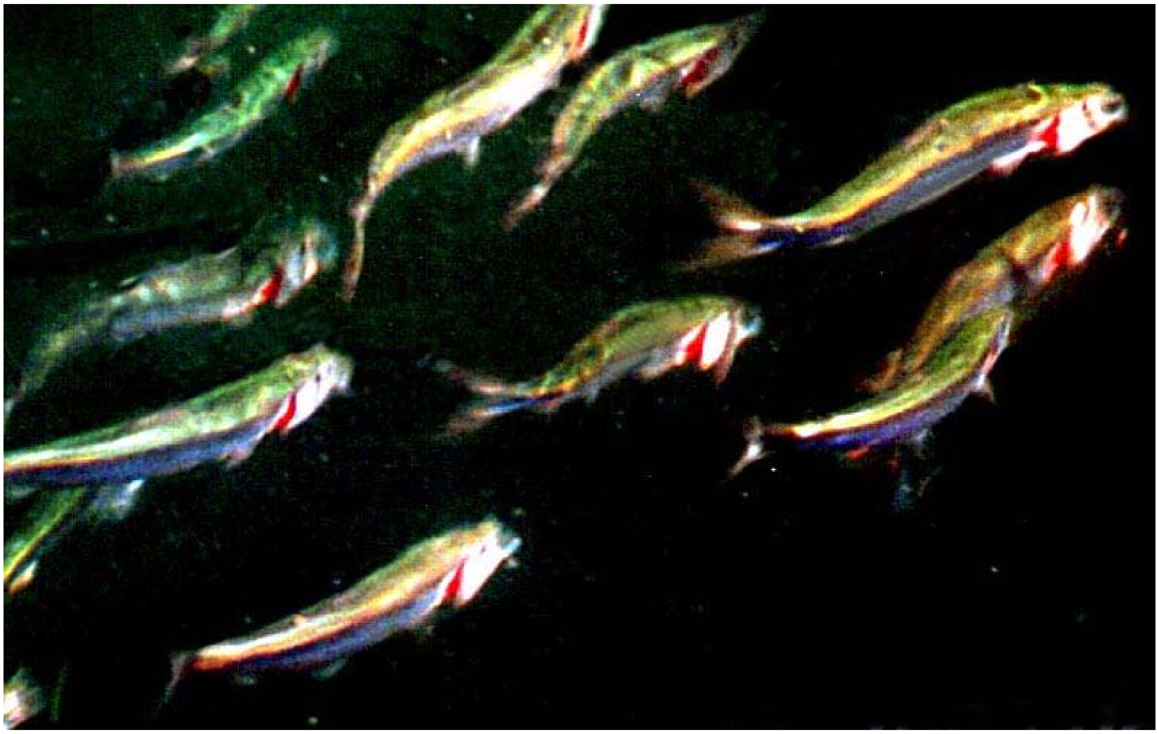
Peruvian anchoveta

Herring are found in the North Sea and the North Atlantic at depths to 200 meters. Important herring fisheries have existed in these areas for centuries. Herring of different sizes and growth rates belong to different populations, each of which have their own migration routes. When spawning, a female produces from 20,000 to 50,000 eggs. After spawning, the herrings are depleted in fat, and migrate back to feeding grounds rich in plankton. Around Iceland, three separate populations of herring were traditionally fished. These stocks collapsed in the late 1960s, although two have since recovered. After the collapse, Iceland turned to capelin, which now account for about half of Iceland's total catch.

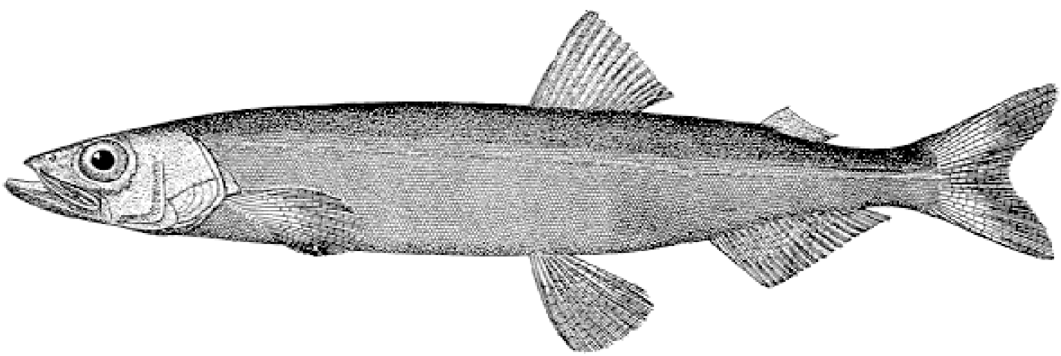
Blue whiting are found in the open ocean and above the continental slope at depths between 100 and 1000 meters. They follow vertical migrations of the zooplankton they feed on to the bottom during daytime and to the surface at night time.

Traditional fisheries for anchovies and sardines have also operated in the Pacific, the Mediterranean, and the southeast Atlantic. The world annual catch of forage fish in recent years has been around 22 million tonnes, or one quarter of the world's total catch.

These schooling Pacific sardines are forage fish



Herrings ram feeding on copepods.



Capelin

Anchovies

Predator fish

Medium size pelagic fishes include trevally, barracuda, flying fish, bonito, mahi mahi and coastal mackerel. Many of these fish hunt forage fish, but are in turn hunted by yet larger pelagic fish. Nearly all fish are predator fish to some measure, and apart from the top predators, the distinction between predator fish and prey or forage fish is somewhat artificial.

Around Europe there are three populations of coastal mackerel. One population migrates to the North Sea, another stays in of the Irish Sea, and the third population migrates southwards along the west coast of Scotland and Ireland. The mackerel's cruise speed is an impressive 10 kilometres per hour.

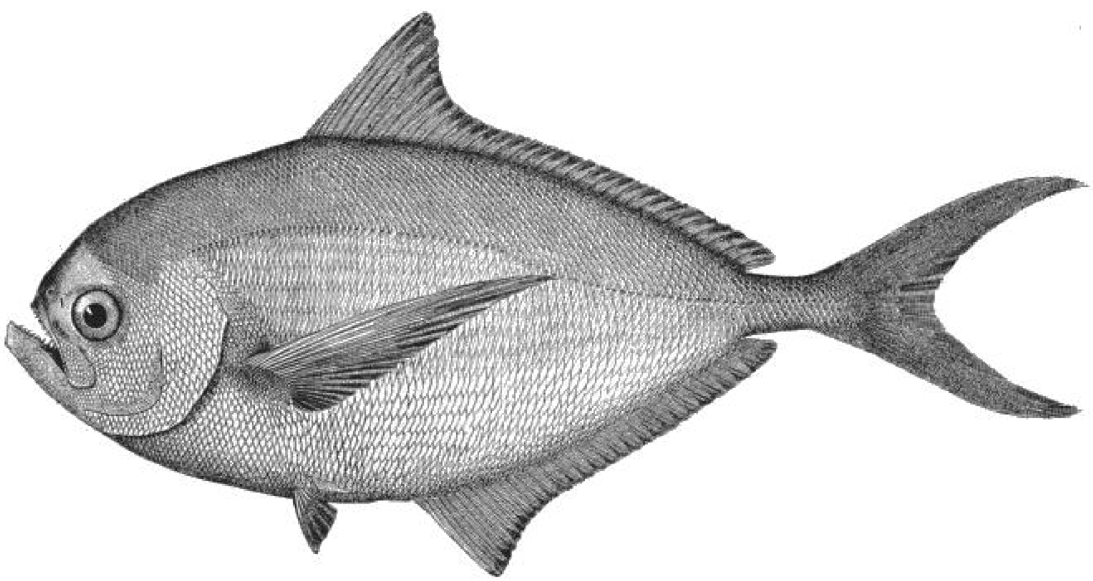
Many large pelagic fish are oceanic nomadic species which undertake long offshore migrations. They feed on small pelagic forage fish, as well as medium sized pelagic fish. At times, they follow their schooling prey, and many species form schools themselves.

Examples of larger pelagic fish are tuna, billfish, king mackerel and sharks and large rays.

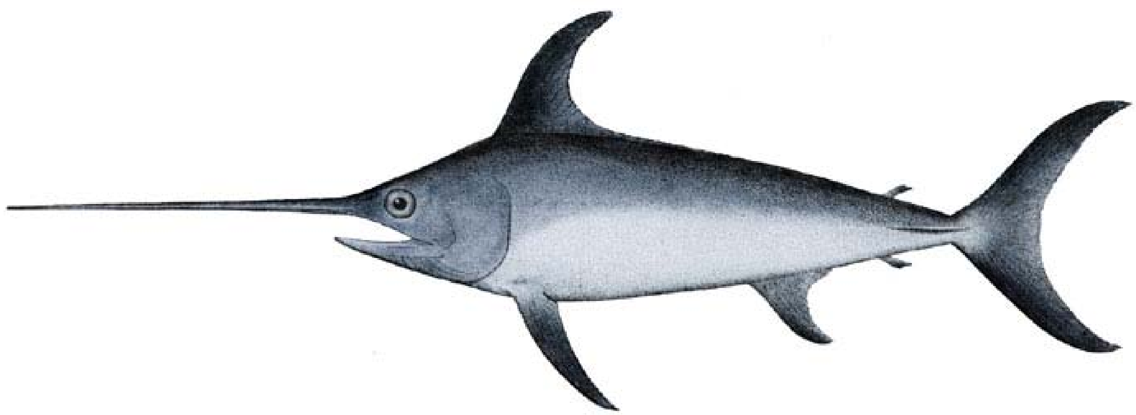
Tuna in particular are of major importance to commercial fisheries. Though tuna migrate across oceans, trying to find them there is not the usual approach. Tuna tend to congregate in areas where food is abundant, along the boundaries of currents, around islands, near seamounts, and in some areas of upwelling along continental slopes. Tuna are captured by several methods: purse seine vessels enclose an entire surface school with special nets, pole and line vessels which use poles baited with other smaller pelagic fish as baitfish, and rafts called fish aggregating devices are set up, because tuna, as well as some other pelagic fish, tend to congregate under floating objects.

Other large pelagic fish are premier game fish, particularly marlin and swordfish.

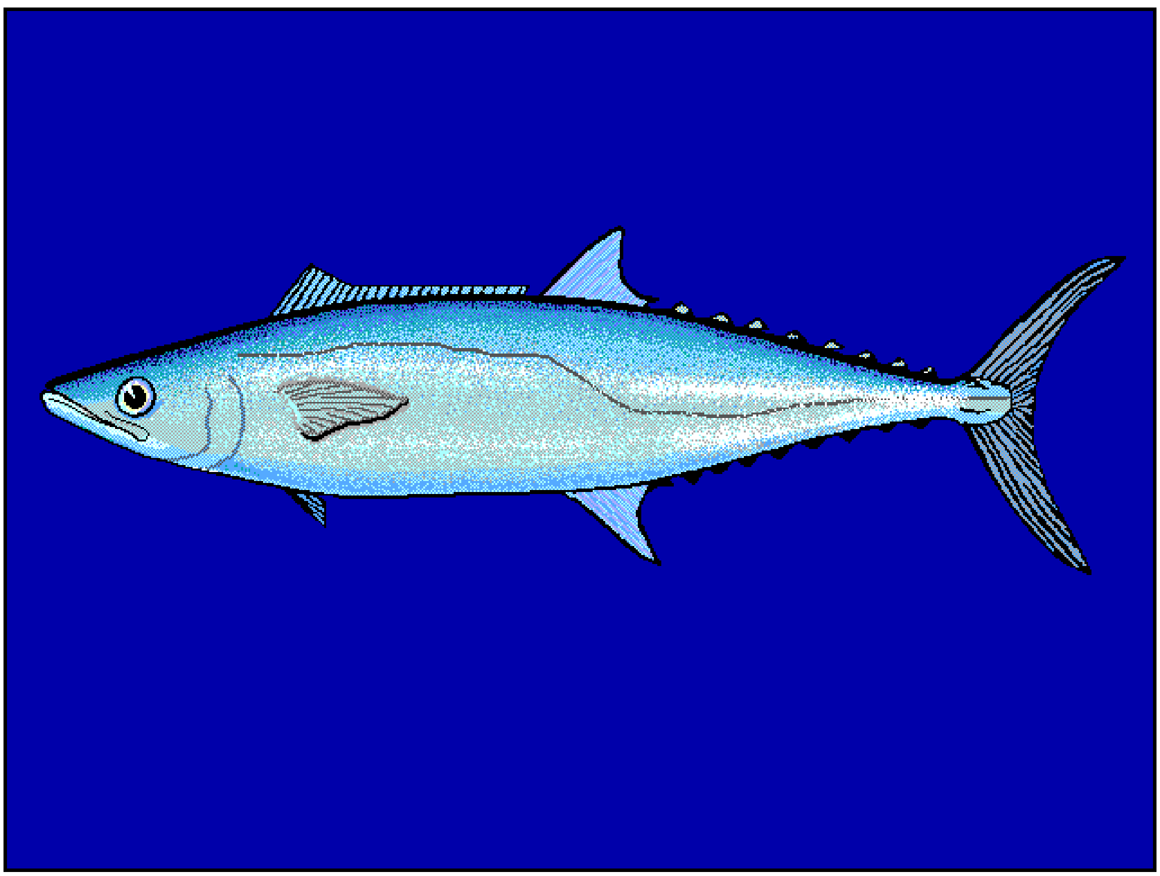
Yellowfin tuna are being fished as a replacement for the now largely depleted Southern bluefin tuna.



Atlantic Pomfret

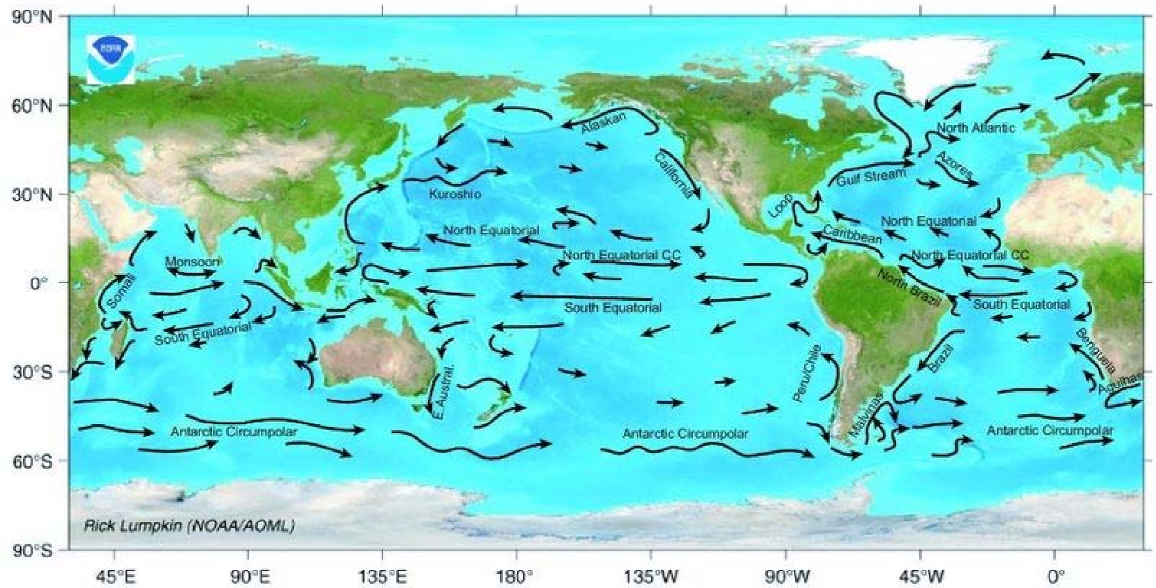


Swordfish

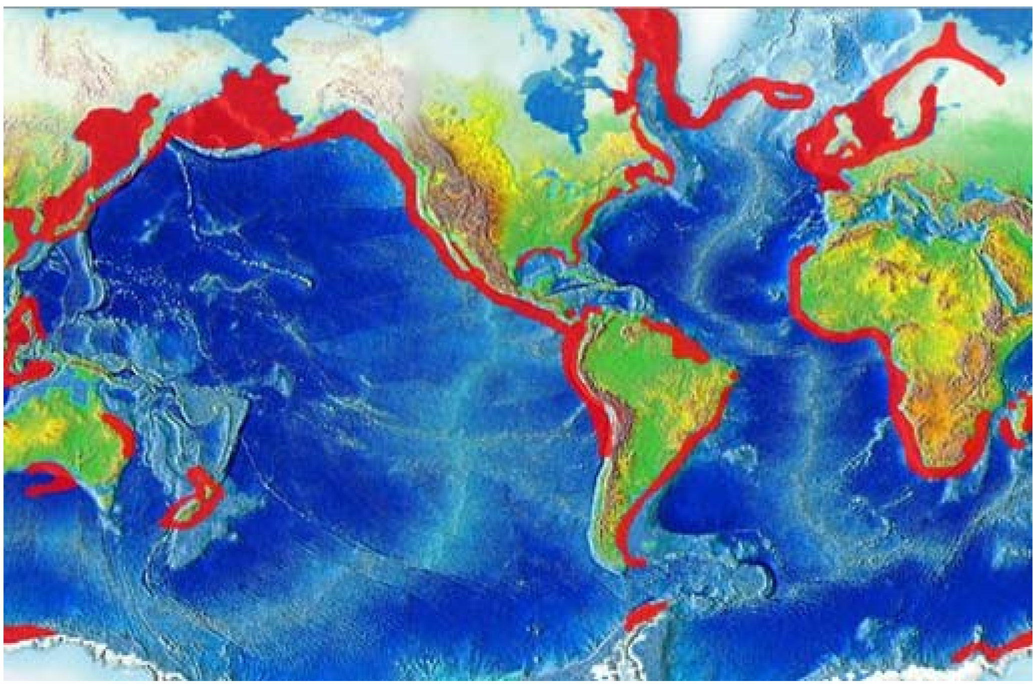


King mackerels cruise on long migrations at 10 kilometres per hour.

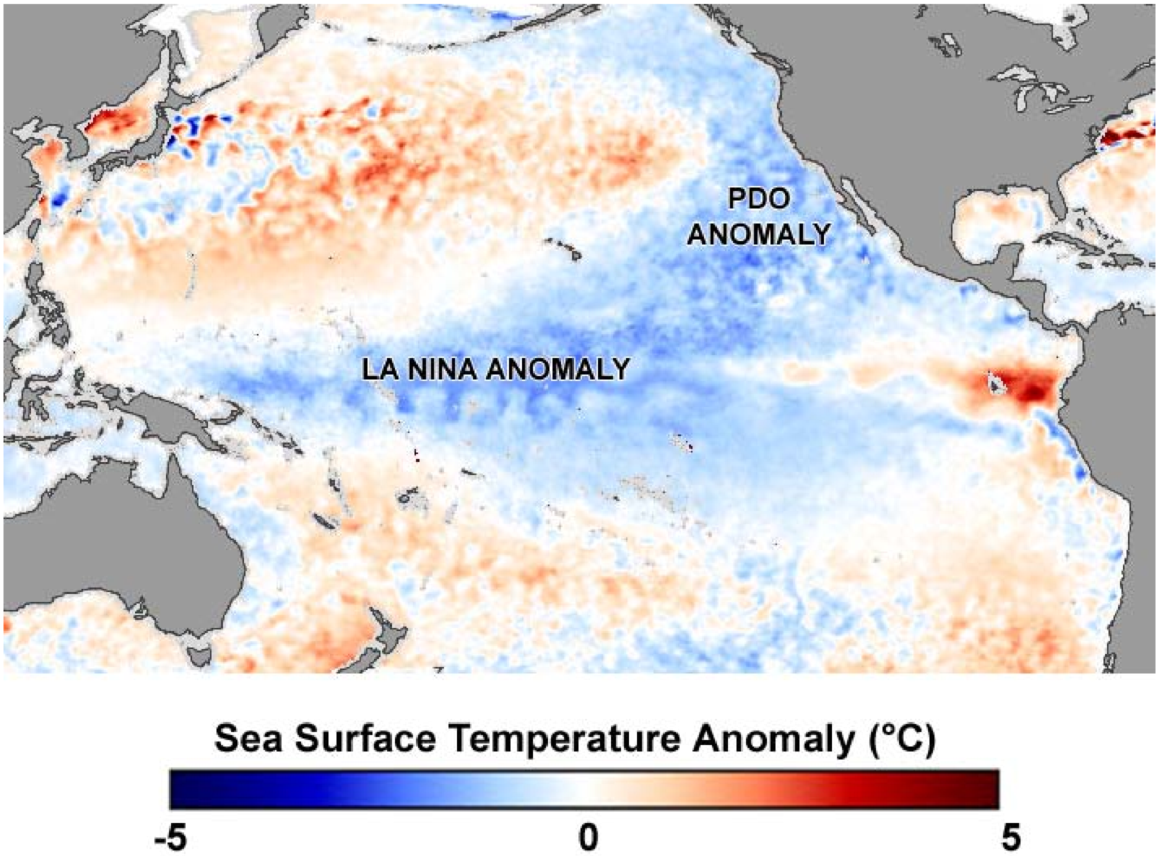
Productivity



Major ocean surface currents



Areas of upwelling in red



La Nina and Pacific decadal anomalies - April 2008

Upwelling occurs both along coastlines and in midocean when a collision of deep ocean currents brings cold water rich in nutrients to the surface. These upwellings support blooms of pytoplankton, which in turn produce zooplankton and support many of the world's main fisheries. If the upwelling fails then fisheries in the area fail.

In the 1960s the Peruvian anchoveta fishery was the world's largest fishery. The anchoveta population was greatly reduced during the 1972 El Niño event, when warm water drifted over the cold Humboldt Current, as part of a 50 year cycle, lowering the depth of the thermocline. The upwelling stopped and phytoplankton production plummeted, as did the anchoveta population, and millions of seabirds, dependant on the anchoveta, died. Since the mid 1980s, the upwelling has resumed, and the Peruvian anchoveta catch levels have returned to the 1960s levels.

Off Japan, the collision of the Oyashio Current with the Kuroshio Current produces nutrient-rich upwellings. Cyclic changes in these currents resulted in a decline in the sardine *sardinops melanosticta* poulations. Fisheries catches fell from 5 million tonnes in 1988 to 280 thousand tonnes in 1998. As a further consequence, bluefin tuna stopped moving into the region to feed.

Ocean currents can shape how fish are distributed, both concentrating and dispersing them. Adjacent ocean currents can define distinct, if shifting, boundaries. These boundaries can even be visible, but usually their presence is marked by rapid changes in salinity, temperature and turbitity.

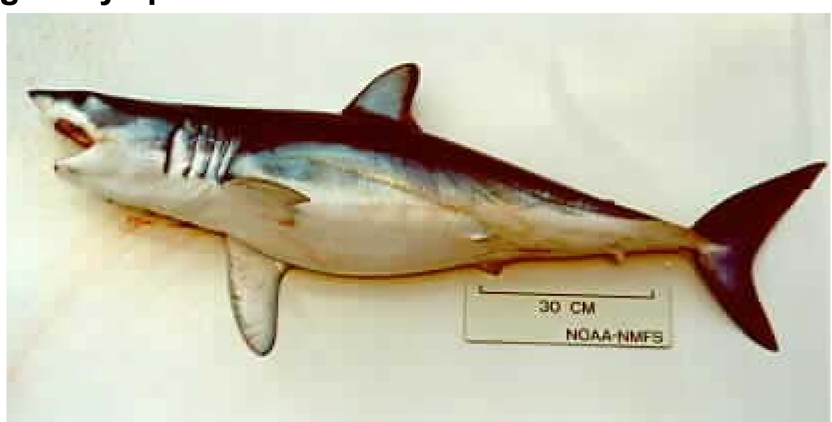
For example, in the Asian northern Pacific, albacore are confined between two current systems. The northern boundary is determined by the cold North Pacific Current and the southern boundary is determined by the North Equatorial Current. To complicate things, their distribution is further modified within the area defined by the two current systems by another current, the Kuroshio Current, whose flows fluctuate seasonally.

Epipelagic fish often spawn in an area where the eggs and larvae drift downstream into suitable feeding areas, and eventually drift into adult feeding areas.

Islands and banks can interact with currents and upwellings in a manner that results in areas of high ocean productivity. Large eddies can form downcurrent or downwind from islands, concentrating plankton. Banks and reefs can intercept deep currents that upwell.

- Scombrids

Highly migratory species



Shortfin mako shark make long seasonal migrations. They appear to follow temperature gradients, and have been recorded travelling more than 4,500 km in one year.

Epipelagic fish generally move long distances between feeding and spawning areas, or as a response to changes in the ocean. Large ocean predators, such as salmon and tuna, can migrate thousands of kilometres, crossing oceans.

In a 2001 study, the movements of northern bluefin tuna from an area off North Carolina were studied with the help of special popup tags. When attached to a tuna, these tags monitored the movements of the tuna for about a year, then freed themselves, and floated to the surface where they transmitted their information to a satellite. The study found that the tuna had four different migration patterns. One group confined itself to the western Atlantic for a year. Another group also stayed mainly in the western Atlantic, but migrated to the Gulf of Mexico for spawning. A third group moved across the Atlantic ocean and back again. The fourth group crossed to the eastern Atlantic and then moved into the Mediterranean Sea for spawning. The study indicates that, while there is some differentiation by spawning areas, there is essentially only one population of northern bluefin tuna, intermixing groups that between them use all of the north Atlantic ocean, the Gulf of Mexico and the Mediterranean Sea.

The term highly migratory species (HMS) is a legal term which has its origins in Article 64 of the United Nations Convention on the Law of the Sea (UNCLOS).

The highly migratory species include: tuna and tuna-like species (albacore, bluefin, bigeye tuna, skipjack, yellowfin, blackfin, little tunny, southern bluefin and bullet), pomfret, marlin, sailfish, swordfish, saury and ocean going sharks, dolphins and other cetaceans.

Essentially, highly migratory species coincide with the larger of the "large pelagic fish", discussed in the previous section, if cetaceans are added and some commercially unimportant fish, such as the sunfish, are excluded. These are high trophic level species which undertake migrations of significant but variable distances across oceans for feeding, often on forage fish, or reproduction, and also have wide geographic distributions. Thus, these species are found both inside the 200-nautical-mile (370 km) exclusive economic zones and in the high seas outside these zones. They are pelagic species, which means they mostly live in the open ocean and do not live near the sea floor, although they may spend part of their life cycle in nearshore waters.

Capture production

According to the Food and Agriculture Organization (FAO), the world harvest in 2005 consisted of 93.2 million tonnes captured by commercial fishing in wild fisheries. Of this total, about 45 percent were pelagic fish. The following table shows the world capture production in tonnes.

Capture production by groups of species in tonnes

Type	Group	1999	2000	2001	2002	2003	2004	2005
Small pelagic fish	Herrings, sardines, anchovies	22 671 427	24 919 239	20 640 734	22 289 332	18 840 389	23 047 541	22 404 769
Large pelagic fish	Tunas, bonitos, billfishes	5 943 593	5 816 647	5 782 841	6 138 999	6 197 087	6 160 868	6 243 122
Other pelagic fish		10 712 994	10 654 041	12 332 170	11 772 320	11 525 390	11 181 871	11 179 641
Cartilaginous fish	Sharks, rays, chimaeras	858 007	870 455	845 854	845 820	880 785	819 012	771 105

Threatened species

In 2009, the International Union for Conservation of Nature (IUCN) produced the first red list for threatened oceanic sharks and rays. They claim that about one third of open ocean sharks and rays are under threat of extinction. There are 64 species of oceanic sharks and rays on the list, including hammerheads, giant devil rays and porbeagle.

Oceanic sharks are captured incidentally by swordfish and tuna high seas fisheries. In the past there were few markets for sharks, which were regarded as worthless bycatch. Now sharks are being increasingly targeted to supply emerging Asian markets, particularly for shark fins, which are used in shark fin soup.

The northwest Atlantic Ocean shark populations are estimated to have declined by 50 percent since the early 1970s. Oceanic sharks are vulnerable because they don't produce many young, and the young can take decades to mature.

The scalloped hammerhead is classified as endangered

The oceanic whitetip shark has declined by 99 percent in the Gulf of Mexico

The devil fish, a large ray, is also threatened

So is the porbeagle shark

In parts of the world the scalloped hammerhead shark has declined by 99 percent since the late 1970s. Its status on the red list is that it is globally endangered, meaning it is near extinction.

Chapter- 10

Shoaling and Schooling

These surgeonfish are shoaling. They are swimming somewhat independently, but in such a way that they stay connected, forming a social group.

These bluestripe snapper are schooling. They are all swimming in the same direction in a coordinated way.

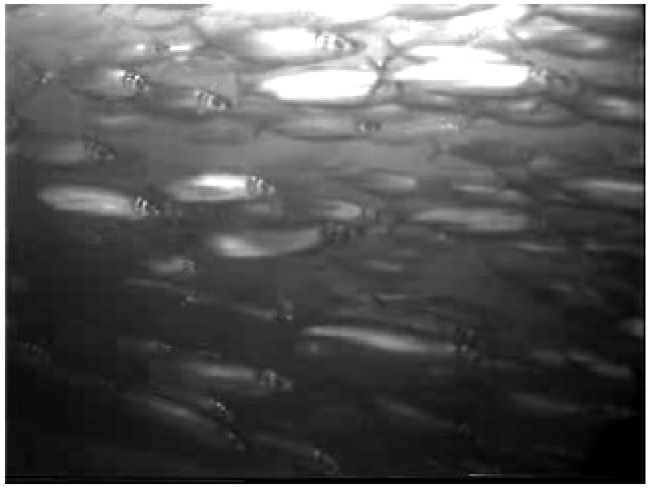
In biology, any group of fish that stay together for social reasons are said to be **shoaling**, and if, in addition, the group is swimming in the same direction in a coordinated manner, they are said to be **schooling**. In common usage, the terms are sometimes used rather loosely. About one quarter of fishes shoal all their lives, and about one half of fishes shoal for part of their lives.

Fish derive many benefits from shoaling behaviour including defence against predators (through better predator detection and by diluting the chance of individual capture), enhanced foraging success, and higher success in finding a mate. It is also likely that fish benefit from shoal membership through increased hydrodynamic efficiency.

Fish use many traits to choose shoalmates. Generally they prefer larger shoals, shoalmates of their own species, shoalmates similar in size and appearance to themselves, healthy fish, and kin (when recognized).

The "oddity effect" posits that any shoal member that stands out in appearance will be preferentially targeted by predators. This may explain why fish prefer to shoal with individuals that resemble themselves. The oddity effect would thus tend to homogenize shoals.

Overview



School of herrings migrating at high speed to their spawning grounds in the Baltic Sea

An **aggregation** of fish is the general term for any collection of fish that have gathered together in some locality. Fish aggregations can be structured or unstructured. An unstructured aggregation might be a group of mixed species and sizes that have gathered randomly near some local resource, such as food or nesting sites.

If, in addition, the aggregation comes together in an interactive, social way, they are said to be **shoaling**. Although shoaling fish can relate to each other in a loose way, with each fish swimming and foraging somewhat independently, they are nonetheless aware of the other members of the group as shown by the way they adjust behaviour such as swimming, so as to remains close to the other fish in the group. Shoaling groups can include fish of disparate sizes and can including mixed-species subgroups.

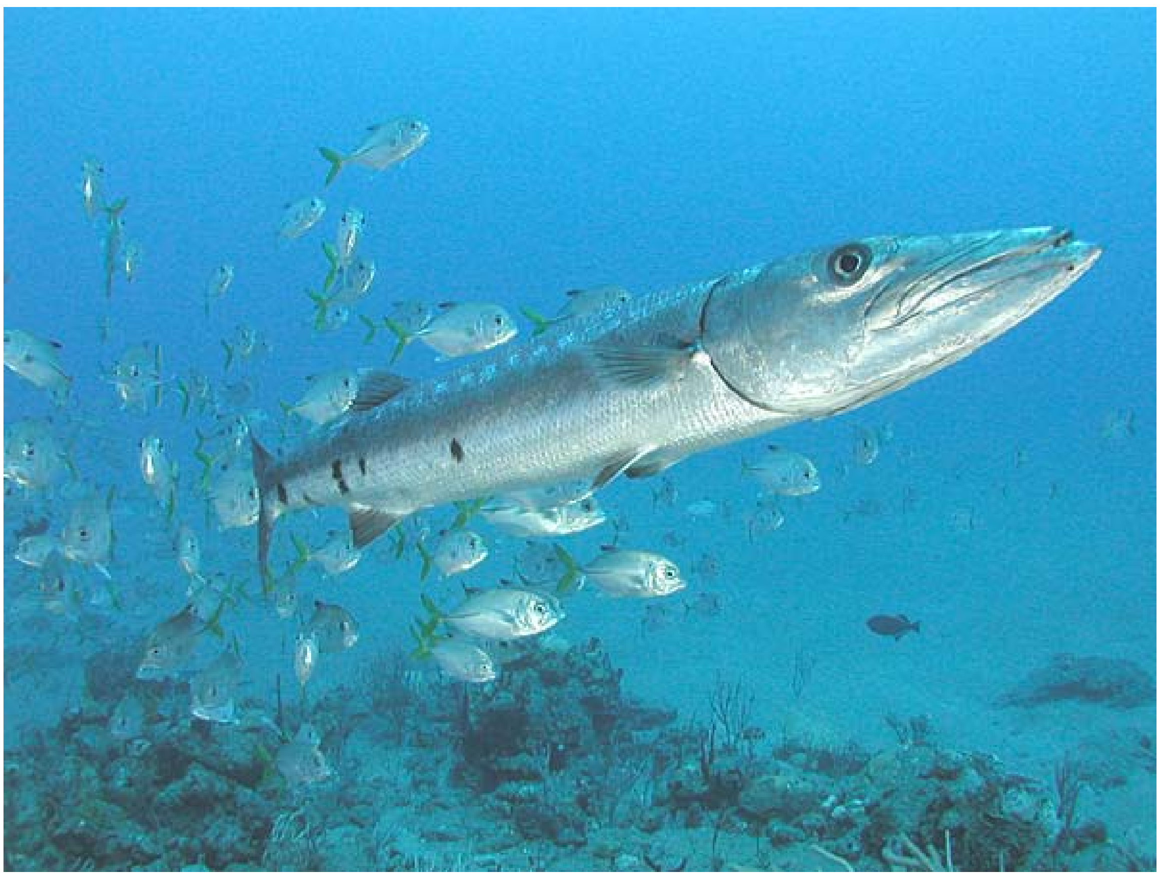
If, as a further addition, the shoal becomes more tightly organised, with the fish synchronising their swimming so they all move at the same speed and in the same direction, then the fish are said to be **schooling**. Schooling fish are usually of the same species and the same age/size. Fish schools move with the individual members precisely spaced from each other. The schools undertake complicated manoeuvres, as though the schools have minds of their own.

Shoaling is a special case of aggregating, and schooling is a special case of shoaling. While schooling and shoaling mean different things within biology, they are often treated as synonyms by non-specialists, with speakers of British English tending to use "shoaling" to describe any grouping of fish, while speakers of American English tend to use "schooling" just as loosely. The intricacies of schooling are far from fully understood, especially the swimming and feeding energetics. Many hypotheses to explain the function of schooling have been suggested, such as better orientation, synchronized hunting, predator confusion and reduced risk of being found. Schooling also has disadvantages, such as excretion buildup in the breathing media and oxygen and food depletion. The way the fish array in the school probably gives energy saving advantages, though this is controversial.

Fish can be obligate or facultative shoalers. Obligate shoalers, such as tunas, herrings and anchovy, spend all of their time shoaling or schooling, and become agitated if separated from the group. Facultative shoalers, such as Atlantic cod, saiths and some carangids, shoal only some of the time, perhaps for reproductive purposes.

Shoaling fish can shift into a disciplined and coordinated school, then shift back to an amorphous shoal within seconds. Such shifts are triggered by changes of activity from feeding, resting, travelling or avoiding predators.

When schooling fish stop to feed, they break ranks and become shoals. Shoals are more vulnerable to predator attack. The shape a shoal or school takes depends on the type of fish and what the fish are doing. Schools that are travelling can form long thin lines, or squares or ovals or amoeboid shapes. Fast moving schools usually form a wedge shape, while shoals that are feeding tend to become circular.



Schools of forage fish often accompany large predator fish. Here a school of jacks accompany a great barracuda.

Forage fish are small fish which are preyed on by larger predators for food. Predators include other larger fish, seabirds and marine mammals. Typical ocean forage fish are small, filter feeding fish such as herring, anchovies and menhaden. Forage fish compensate for their small size by forming schools. Some swim in synchronised grids with their mouths open so they can efficiently filter feed on plankton. These schools can become huge, moving along coastlines and migrating across open oceans. The shoals are concentrated fuel resources for the great marine predators.

These sometimes immense gatherings fuel the ocean food web. Most forage fish are pelagic fish, which means they form their schools in open water, and not on or near the bottom (demersal fish). Forage fish are short-lived, and go mostly unnoticed by humans, apart from an occasional support role in a documentary about a great ocean predator. The predators are keenly focused on the shoals, acutely aware of their numbers and whereabouts, and make migrations themselves, often in schools of their own, that can span thousands of miles to connect with, or stay connected with them.

Herring are among the more spectacular schooling fish. They aggregate together in huge numbers. The largest schools are often formed during migrations by merging with smaller schools. “Chains” of schools one hundred kilometres long have been observed of mullet migrating in the Caspian Sea. Radakov estimated herring schools in the North Atlantic can occupy up to 4.8 cubic kilometres with fish densities between 0.5 and 1.0 fish/cubic metre. That's about three billion fish in one school. These schools move along coastlines and traverse the open oceans. Herring schools in general have very precise arrangements which allow the school to maintain relatively constant cruising speeds. Herrings have excellent hearing, and their schools react very fast to a predator. The herrings keep a certain distance from a moving scuba diver or cruising predator like a killer whale, forming a vacuole which looks like a doughnut from a spotter plane.

Many species of large predatory fish also school, including many highly migratory fish, such as tuna and some ocean going sharks. Cetaceans such as dolphins, porpoises and whales, operate in organised social groups called **pods**.

"Shoaling behaviour is generally described as a trade-off between the anti-predator benefits of living in groups and the costs of increased foraging competition." Landa (1998) argues that the cumulative advantages of shoaling, as elaborated below, are strong selective inducements for fish to join shoals. Parrish et al. (2002) argue similarly that schooling is a classic example of emergence, where there are properties that are possessed by the school but not by the individual fish. Emergent properties give an evolutionary advantage to members of the school which non members do not receive.

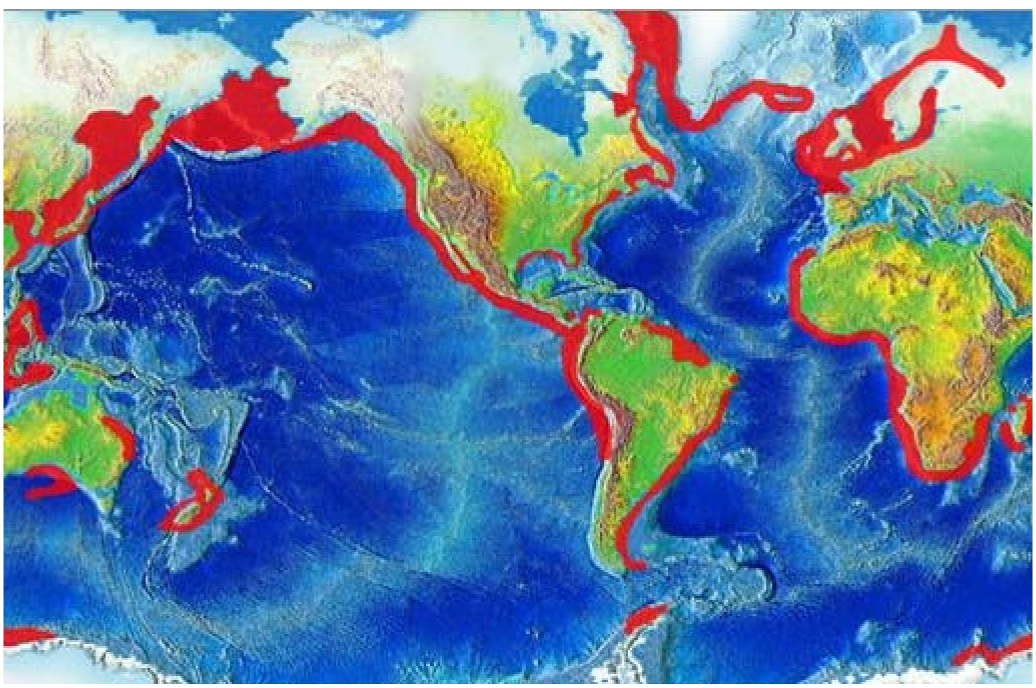
Social interaction

Support for the social and genetic function of aggregations, especially those formed by fish, can be seen in several aspects of their behaviour. For instance, experiments have shown that individual fish removed from a school will have a higher respiratory rate than those found in the school. This effect has been attributed to stress, and the effect of being with conspecifics therefore appears to be a calming one and a powerful social motivation for remaining in an aggregation. Herring, for instance, will become very agitated if they are isolated from conspecifics. Because of their adaptation to schooling behaviour they are rarely displayed in aquaria. Even with the best facilities aquaria can offer they become fragile and sluggish compared to their quivering energy in wild schools.

Foraging advantages

It has also been proposed that swimming in groups enhances foraging success. This ability was demonstrated by Pitcher and others in their study of foraging behaviour in shoaling cyprinids. In this study, the time it took for groups of minnows and goldfish to find a patch of food was quantified. The number of fishes in the groups was varied, and a statistically significant decrease in the amount of time necessary for larger groups to find food was established. Further support for an enhanced foraging capability of schools is seen in the structure of schools of predatory fish. Partridge and others analysed the school structure of Atlantic bluefin tuna from aerial photographs and found that the school assumed a parabolic shape, a fact that was suggestive of cooperative hunting in this species.

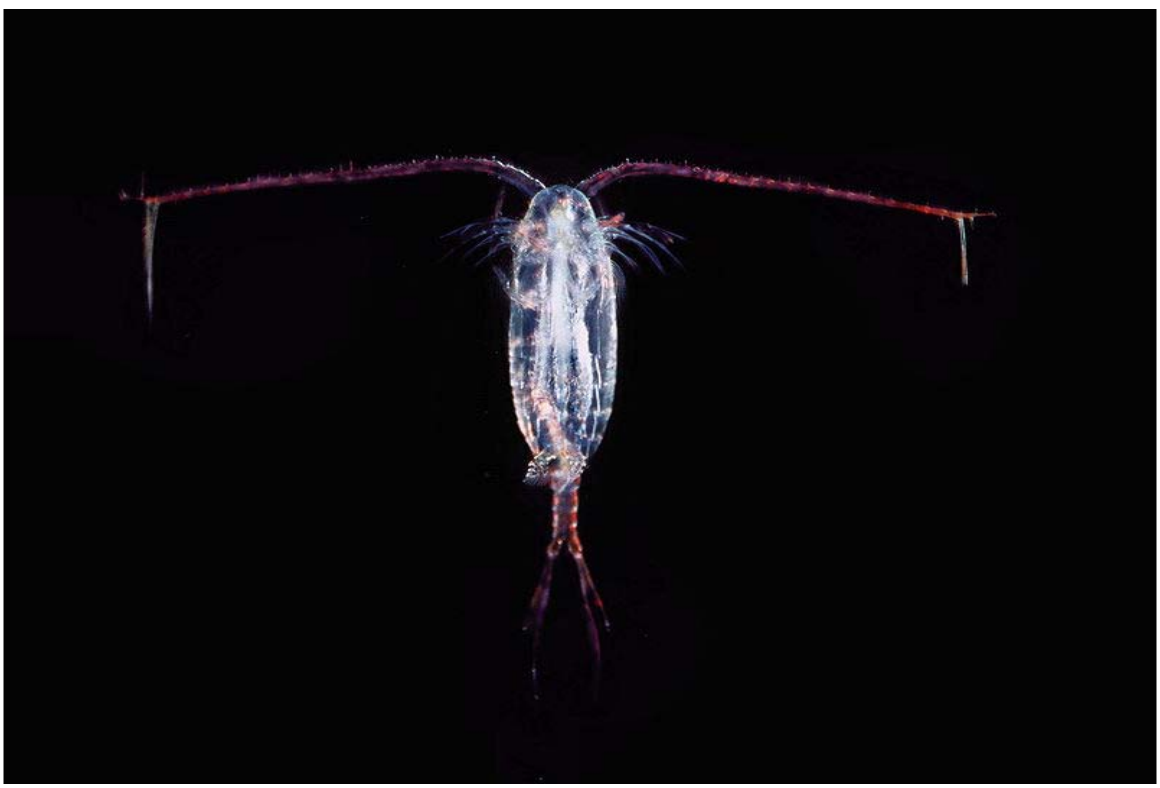
"The reason for this is the presence of many eyes searching for the food. Fish in shoals “share” information by monitoring each other’s behaviour closely. Feeding behaviour in one fish quickly stimulates food-searching behaviour in others."



Some coastal upwellings (red) provide plankton rich feeding grounds for shoals of forage fish, which in turn attract larger predator fish.

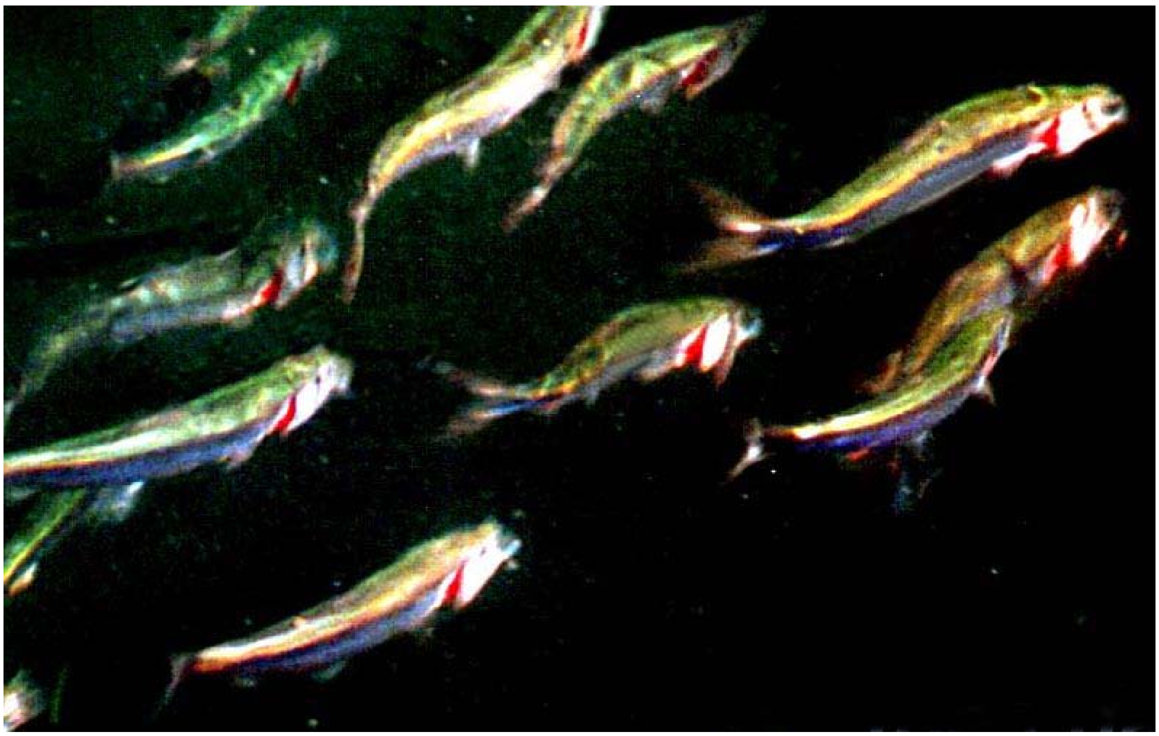
Fertile feeding grounds for forage fish are provided by ocean upwellings. Oceanic gyres are large-scale ocean currents caused by the Coriolis effect. Wind-driven surface currents interact with these gyres and the underwater topography, such as seamounts, fishing banks, and the edge of continental shelves, to produce downwellings and upwellings. These can transport nutrients which plankton thrive on. The result can be rich feeding grounds attractive to the plankton feeding forage fish. In turn, the forage fish themselves become a feeding ground for larger predator fish. Most upwellings are coastal, and many of them support some of the most productive fisheries in the world. Regions of notable upwelling include coastal Peru, Chile, Arabian Sea, western South Africa, eastern New Zealand and the California coast.

Copepods, the primary zooplankton, are a major item on the forage fish menu. They are a group of small crustaceans found in ocean and freshwater habitats. Copepods are typically one millimetre (0.04 in) to two millimetres (0.08 in) long, with a teardrop shaped body. Some scientists say they form the largest animal biomass on the planet. Copepods are very alert and evasive. They have large antennae (see photo below left). When they spread their antennae they can sense the pressure wave from an approaching fish and jump with great speed over a few centimeters. If copepod concentrations reach high levels, schooling herrings adopt a method called "ram feeding". In the photo below, herring ram feed on a school of copepods. They swim with their mouth wide open and their opercula fully expanded.

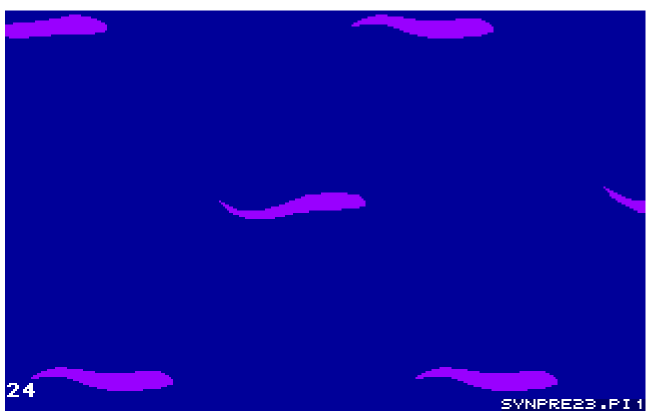


This copepod has its antenna spread. The antenna detects the pressure wave of an approaching fish.

Copepods are a major food source for forage fish like this Atlantic herring



School of herrings ram feeding on a school of copepods.

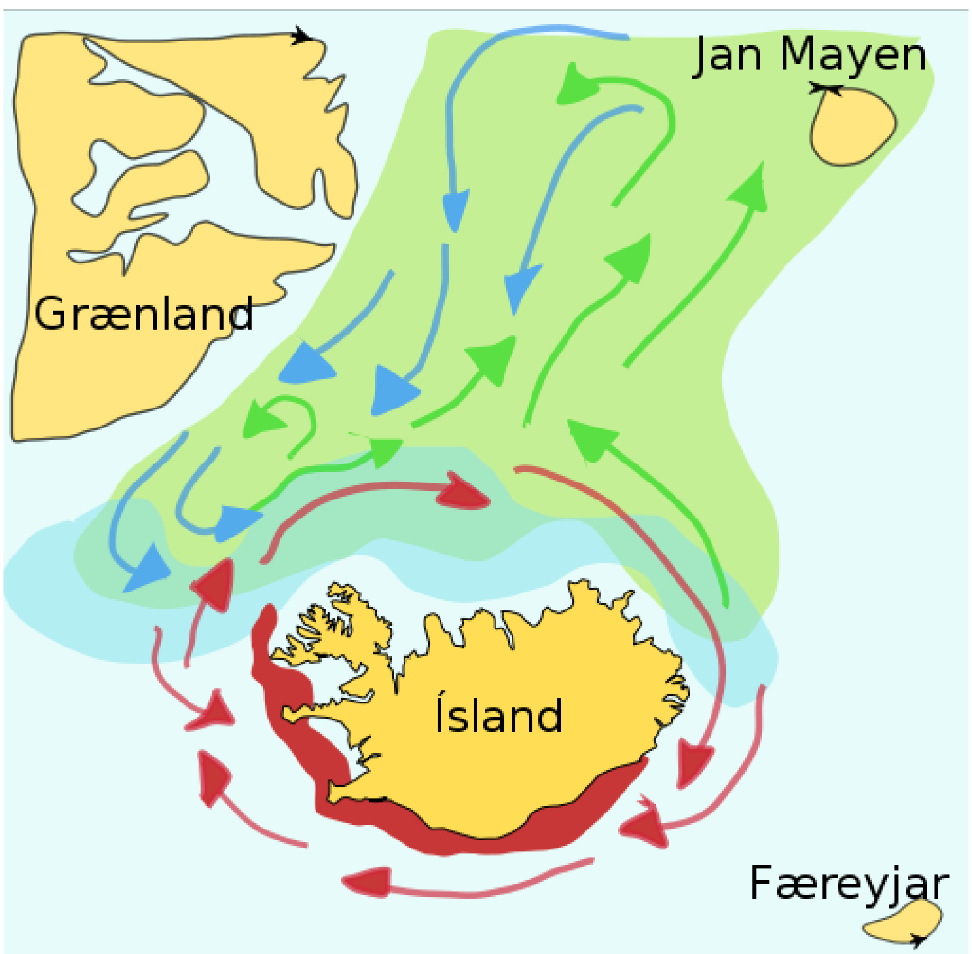


How herrings hunting in a synchronised way can capture the very alert and evasive copepod.

The fish swim in a grid where the distance between them is the same as the jump length of their prey, as indicated in the image above right. In the image, juvenile herring hunt the copepods in this synchronised way. The copepods sense with their antennae the pressure-wave of an approaching herring and react with a fast escape jump. The length of the jump is fairly constant. The fish align themselves in a grid with this characteristic jump length. A copepod can dart about 80 times before it tires. After a jump, it takes it 60 milliseconds to spread its antennae again, and this time delay becomes its undoing, as the almost endless stream of herrings allows a herring to eventually snap the copepod. A single juvenile herring could never catch a large copepod.

Reproductive advantages

A third proposed benefit of fish groups is that they serve a reproductive function. They provide increased access to potential mates, since finding a mate in a shoal does not take much energy. And for migrating fish that navigate long distances to spawn, it is likely that the navigation of the shoal, with an input from all the shoal members, will be better than that taken by an individual fish."



Migration of Icelandic capelin

Forage fish often make great migrations between their spawning, feeding and nursery grounds. Schools of a particular stock usually travel in a triangle between these grounds. For example, one stock of herrings have their spawning ground in southern Norway, their feeding ground in Iceland, and their nursery ground in northern Norway. Wide triangular journeys such as these may be important because forage fish, when feeding, cannot distinguish their own offspring.

Capelin are a forage fish of the smelt family found in the Atlantic and Arctic oceans. In summer, they graze on dense swarms of plankton at the edge of the ice shelf. Larger capelin also eat krill and other crustaceans. The capelin move inshore in large schools to spawn and migrate in spring and summer to feed in plankton rich areas between Iceland, Greenland, and Jan Mayen. The migration is affected by ocean currents. Around Iceland maturing capelin make large northward feeding migrations in spring and summer. The return migration takes place in September to November. The spawning migration starts north of Iceland in December or January.

The diagram on the right shows the main spawning grounds and larval drift routes. Capelin on the way to feeding grounds is coloured green, capelin on the way back is blue, and the breeding grounds are red.

Hydrodynamic efficiency

This theory states that groups of fish may save energy when swimming together, much in the way that bicyclists may draft one another in a peloton. Geese flying in a Vee formation are also thought to save energy by flying in the updraft of the wingtip vortex generated by the previous animal in the formation. Increased efficiencies in swimming in groups have been proposed for schools of fish and Antarctic krill.

It would seem reasonable to think that the regular spacing and size uniformity of fish in schools would result in hydrodynamic efficiencies. However, experiments in the laboratory have failed to find any gains from the hydrodynamic lift created by the neighbours of a fish within a school, though it is still thought that efficiency gains do occur in the wild. Landa (1998) argues that the leader of a school constantly changes, because while being in the body of a school gives a hydrodynamic advantage, being the leader means you are the first to the food.

Predator avoidance

Schooling predator bluefin trevally size up schooling anchovies

It is commonly observed that schooling fish are particularly in danger of being eaten if they are separated from the school. Several anti-predator functions of fish schools have been proposed.

- **Confusion effect** – One potential method by which fish schools may thwart predators is the 'predator confusion effect' proposed and demonstrated by Milinksi and Heller (1978). This theory is based on the idea that it becomes difficult for predators to pick out individual prey from groups because the many moving targets create a sensory overload of the predator's visual channel. "Shoaling fish are the same size and silvery, so it is difficult for a visually oriented predator to pick an individual out of a mass of twisting, flashing fish and then have enough time to grab its prey before it disappears into the shoal."
- **Many eyes effect** – A second potential anti-predator effect of animal aggregations is the 'many eyes' hypothesis. This theory states that as the size of the group increases, the task of scanning the environment for predators can be spread out over many individuals. Not only does this mass collaboration presumably provide a higher level of vigilance, it could also allow more time for individual feeding.
- **Dilution effect** – A third hypothesis for an anti-predatory effect of fish schools is the 'encounter dilution' effect. The dilution effect is an elaboration of safety in

> numbers, and interacts with the confusion effect. A given predator attack will eat a smaller proportion of a large shoal than a small shoal. Hamilton proposed that animals aggregate because of a “selfish” avoidance of a predator and was thus a form of cover-seeking. Another formulation of the theory was given by Turner and Pitcher and was viewed as a combination of detection and attack probabilities. In the detection component of the theory, it was suggested that potential prey might benefit by living together since a predator is less likely to chance upon a single group than a scattered distribution. In the attack component, it was thought that an attacking predator is less likely to eat a particular fish when a greater number of fish are present. In sum, a fish has an advantage if it is in the larger of two groups, assuming that the probability of detection and attack does not increase disproportionately with the size of the group.

Schooling forage fish are subject to constant attacks by predators. An example is the attacks that take place during the African sardine run. The African sardine run is a spectacular migration by millions of silvery sardines along the southern coastline of Africa. In terms of biomass, the sardine run could rival East Africa's great wildebeest migration.

Sardines have a short life-cycle, living only two or three years. Adult sardines, about two years old, mass on the Agulhas Bank where they spawn during spring and summer, releasing tens of thousands of eggs into the water. The adult sardines then make their way in hundreds of shoals towards the sub-tropical waters of the Indian Ocean. A larger shoal might be 7 kilometres (4 mi) long, 1.5 kilometres (1 mi) wide and 30 meters (100 ft) deep. Huge numbers of sharks, dolphins, tuna, sailfish, Cape fur seals and even killer whales congregate and follow the shoals, creating a feeding frenzy along the coastline.

When threatened, sardines instinctively group together and create massive "bait balls". Bait balls can be up to 20 meters (70 ft) in diameter. They are short lived, seldom lasting longer than 20 minutes.

The fish eggs, left behind at the Agulhas Banks, drift north west with the current into waters off the west coast, where the larvae develop into juvenile fish. When they are old enough, they aggregate into dense shoals and migrate southwards, returning to the Agulhas banks in order to restart the cycle.

Predator countermeasures

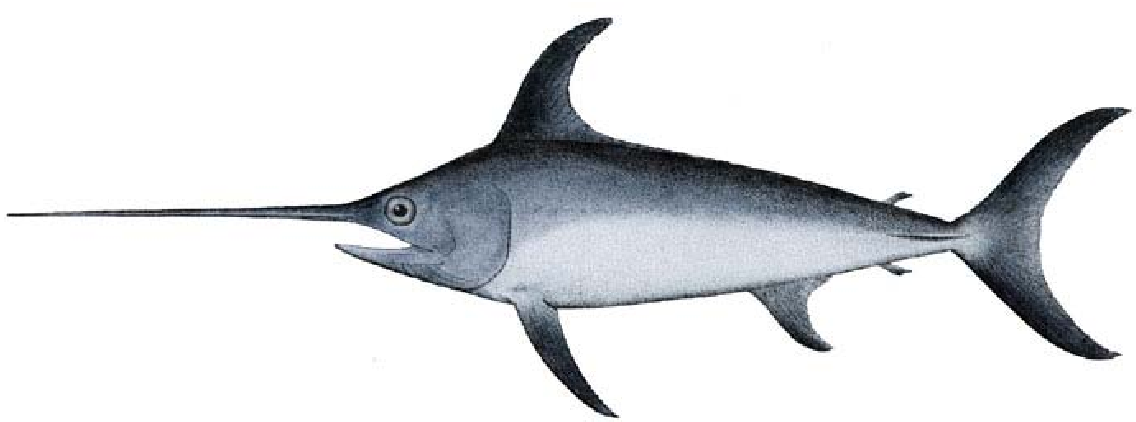
Gannets "divebomb" at high speed.

Predators have devised various countermeasures to undermine the defensive shoaling and schooling manoeuvres of forage fish. Some of these predators, such as dolphins, hunt in groups of their own. One technique employed by many dolphin species is herding, where a pod will control a school of fish while individual members take turns ploughing through and feeding on the more tightly-packed school (a formation commonly known as a "bait ball.") Corralling is a method where fish are chased to shallow water where they are more easily captured. In South Carolina, the Atlantic bottlenose dolphin takes this one step further with what has become known as strand feeding, where the fish are driven onto mud banks and retrieved from there.

During the sardine run, as many as 18,000 dolphins, behaving like sheepdogs, herd the sardines into bait balls, or corral them in shallow water. Once rounded up, the dolphins and other predators take turns ploughing through the bait balls, gorging on the fish as they sweep through. Seabirds also attack them from above, flocks of gannets, cormorants, terns and gulls. Some of these seabirds plummet from heights of 30 metres (100 feet), plunging through the water leaving vapour-like trails behind like fighter planes. Gannets plunge into the water at up to 100 kilometres per hour (60 mph). They have air sacs under their skin in their face and chest which act like bubble-wrap, cushioning the impact with the water.

The sailfish raises its sail to make it appear much larger so it can "herd" a school of fish or squid. Swordfish charge at high speed through forage fish schools, slashing with their swords to kill or stun prey. They then turn and return to consume their "catch".

Sailfish herd with their sails.



Swordfish slash with their swords.

Thresher shark strike with their tails

Spinner shark spin on their axis

Thresher sharks use their long tails to stun shoaling fishes. Before striking, the sharks compact schools of prey by swimming around them and splashing the water with its tail, often in pairs or small groups. Threshers swim in circles to drive schooling prey into a compact mass, before striking them sharply with the upper lobe of its tail to stun them.

Spinner sharks charge vertically through the school, spinning on their axis with their mouths open and snapping all around. The shark's momentum at the end of these spiralling runs often carries it into the air.

When a bait ball has formed, a whalebone whale can quickly shovel up most of the fish in a few passes with its mouth open.

How fish school

Fish schools swim in disciplined phalanxes, with some species, such as herrings, able to stream up and down at impressive speeds, twisting this way and that, and making startling changes in the shape of the school, without collisions. It is as if their motions are choreographed, though they are not. There must be very fast response systems to allow the fish to do this. Young fish practise schooling techniques in pairs, and then in larger groups as their techniques and senses mature. The schooling behaviour develops instinctively and is not learnt from older fish. To school the way they do, fish require sensory systems which can respond with great speed to small changes in their position relative to their neighbour. Most schools lose their schooling abilities after dark, and just shoal. This indicates that vision is important to schooling. The importance of vision is also indicated by the behaviour of fish who have been temporarily blinded. Schooling species have eyes on the sides of their heads, which means they can easily see their neighbours. Also, schooling species often have "schooling marks" on their shoulders or the base of their tails, or visually prominent stripes, which provide reference marks when schooling, similar in function to passive markers in artificial motion capture. However fish without these markers will still engage in schooling behaviour, though perhaps not as efficiently.

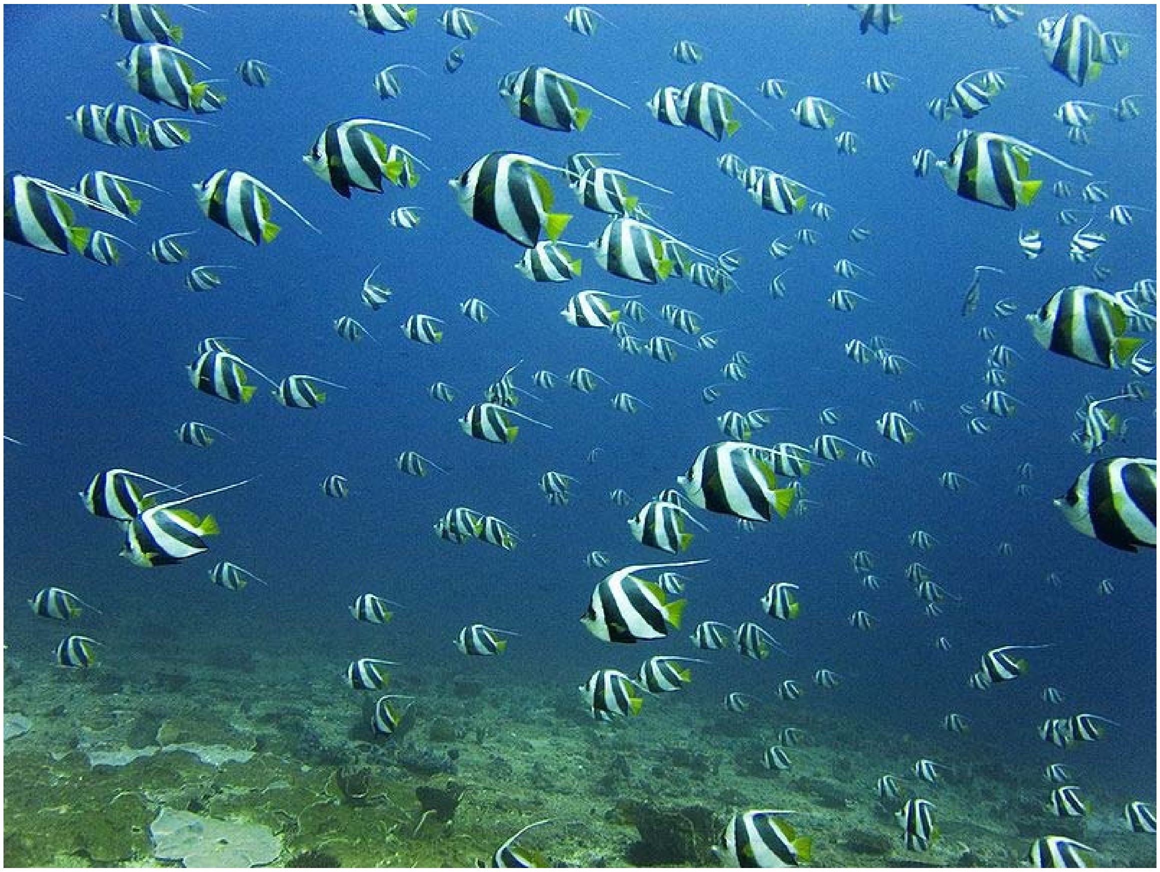
Other senses are also used. The lateral line is a line running along each side of the fish from the gill covers to the base of the tail. In laboratory experiments the lateral lines of schooling fish have been removed. They swam closer, leading to a theory that the lateral lines provide additional stimuli input when the fish get too close. The lateral-line system is very sensitive to changes in water currents and vibration in the water. It uses receptors called neuromasts, each of which is composed of a group of hair cells. The hairs are surrounded by a protruding jelly-like cupula, typically 0.1 to 0.2 mm long. The hair cells in the lateral line are similar to the hair cells inside the vertebrate inner ear, indicating that the lateral line and the inner ear share a common origin. Pheromones or sound may also play a part but supporting evidence has not been found so far.

Describing shoal structure

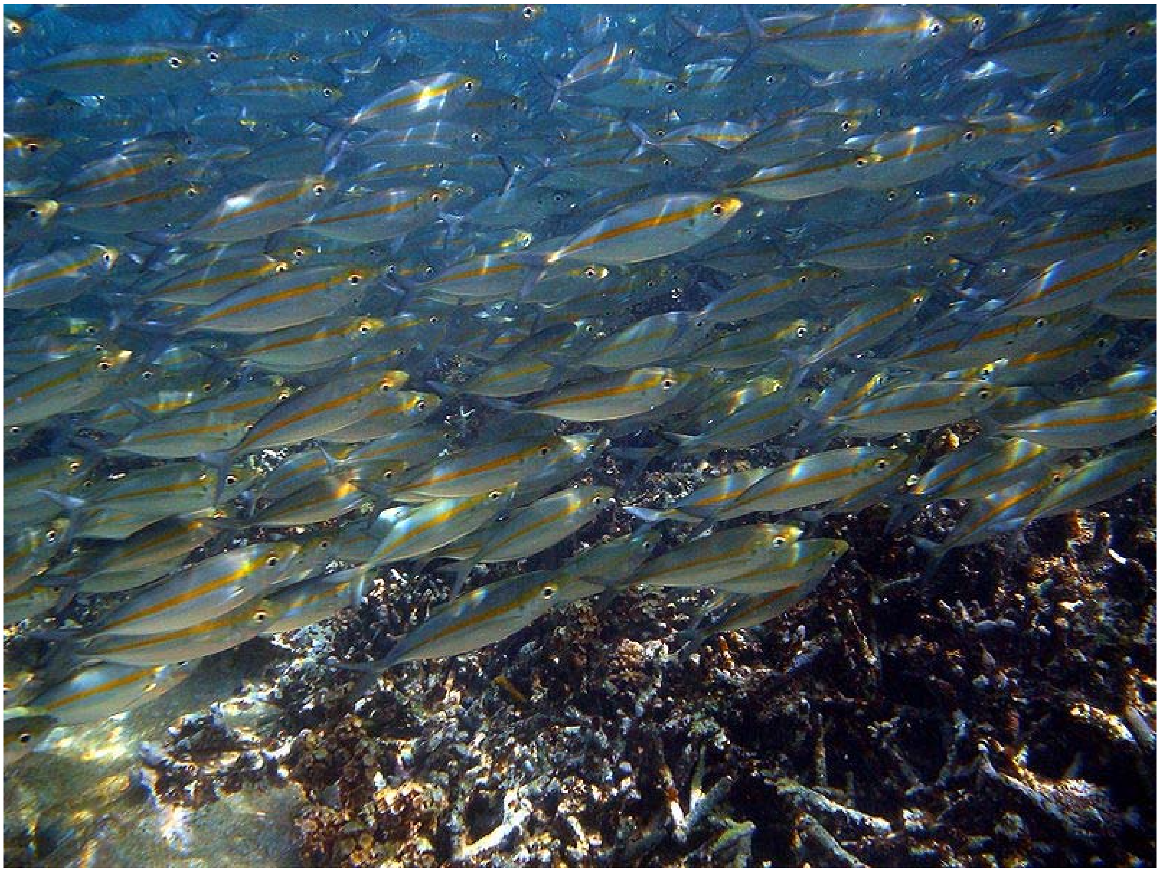
It is difficult to observe and describe the three dimensional structure of real world fish shoals because of the large number of fish involved. Techniques include the use of recent advances in fisheries acoustics.

Parameters defining a fish shoal include:

- Shoal size – The number of fish in the shoal.
- Density – The density of a fish shoal is the number of fish divided by the volume occupied by the shoal. Density is not necessarily a constant throughout the group. Fish in schools typically have a density of about one fish per cube of body length.

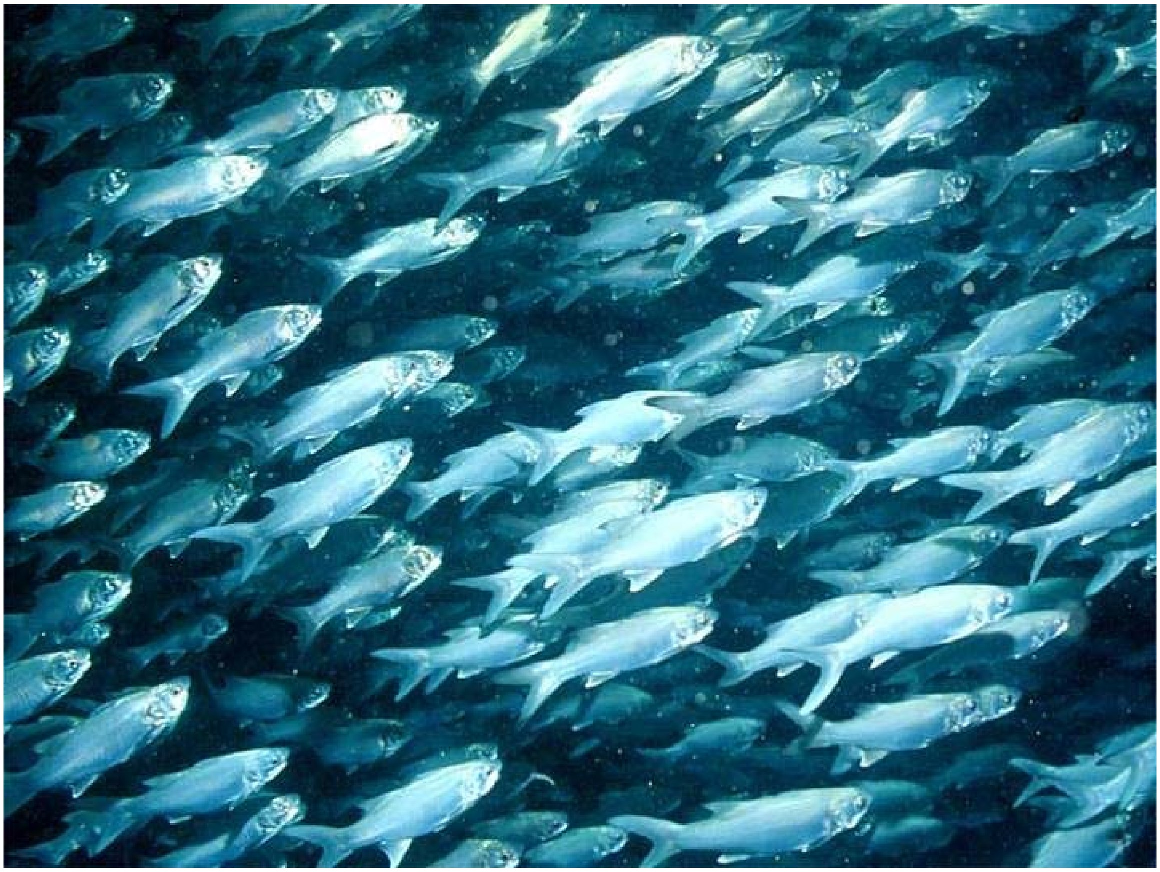


Low density



High density

Low polarity



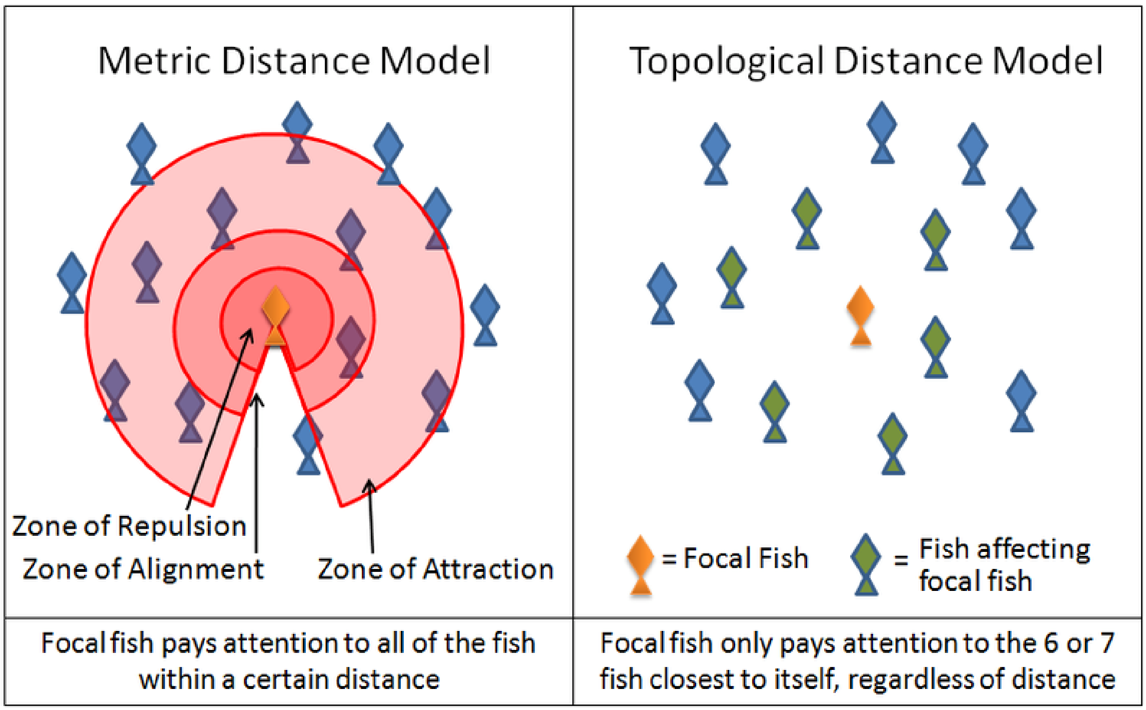
High polarity

- Polarity – The group polarity describes the extent to which the fish are all pointing in the same direction. In order to determine this parameter, the average orientation of all animals in the group is determined. For each animal, the angular difference between its orientation and the group orientation is then found. The group polarity is the average of these differences (Viscido 2004).
- Nearest neighbour distance – The nearest neighbour distance (NND) describes the distance between the centroid of one fish (the focal fish) and the centroid of the fish nearest to the focal fish. This parameter can be found for each fish in an aggregation and then averaged. Care must be taken to account for the fish located at the edge of an fish aggregation, since these fish have no neighbour in one direction. The NND is also related to the packing density. For schooling fish the NND is usually between one-half and one body length.
- Nearest neighbour position – In a polar coordinate system, the nearest neighbour position describes the angle and distance of the nearest neighbour to a focal fish.
- Packing fraction – The packing fraction is a parameter borrowed from physics to define the organization (or state i.e. solid, liquid, or gas) of 3D fish groups. It is an alternative measure to density. In this parameter, the aggregation is idealized as an ensemble of solid spheres, with each fish at the center of a sphere. The packing fraction is defined as the ratio of the total volume occupied by all individual spheres divided by the global volume of the aggregation (Cavagna 2008). Values

range from zero to one, where a small packing fraction represents a dilute system like a gas.

- Integrated conditional density – This parameter measures the density at various length scales and therefore describes the homogeneity of density throughout an animal group.
- Pair distribution function – This parameter is usually used in physics to characterize the degree of spatial order in a system of particles. It also describes the density, but this measure describes the density at a distance away from a given point. Cavagna et al. found that flocks of starlings exhibited more structure than a gas but less than a liquid.

Modelling school behaviour



A diagram illustrating the difference between 'metric distance' and 'topological distance' in reference to fish schools

The observational approach is complemented by the mathematical modelling of schools. The most common mathematical models of schools instruct the individual animals to follow three rules:

1. Move in the same direction as your neighbour
2. Remain close to your neighbours
3. Avoid collisions with your neighbours

An example of such a simulation is the boids program created by Craig Reynolds in 1986. Another is the self propelled particle model. Many current models use variations on these rules. For instance, many models implement these three rules through layered zones around each fish.

1. In the zone of repulsion very close to the fish, the focal fish will seek to distance itself from its neighbours in order to avoid a collision.
2. In the slightly further away zone of alignment, a focal fish will seek to align its direction of motion with its neighbours.
3. In the outmost zone of attraction, which extends as far away from the focal fish as it is able to sense, the focal fish will seek to move towards a neighbour.

The shape of these zones will necessarily be affected by the sensory capabilities of the fish. Fish rely on both vision and on hydrodynamic signals relayed through its lateral line. Antarctic krill rely on vision and on hydrodynamic signals relayed through its antennae.

In a masters thesis published in 2008, Moshi Charnell produced schooling behaviour without using the alignment matching component of an individuals behaviour. His model reduces the three basic rules to the following two rules:

1. Remain close to your neighbours
2. Avoid collisions with your neighbours

In a paper published in 2009, researchers from Iceland recount their application of an interacting particle model to the capelin stock around Iceland, successfully predicting the spawning migration route for 2008.

Mapping the formation of schools

In 2009, building on recent advances in acoustic imaging, a group of MIT researchers observed for "the first time the formation and subsequent migration of a huge shoal of fish." The results provide the first field confirmation of general theories about how large groups behave, from locust swarms to bird flocks.

The researchers imaged spawning Atlantic herring off Georges Bank. They found that the fish come together from deeper water in the evening, shoaling in a disordered way. A chain reaction triggers when the population density reaches a critical value, like an audience wave travelling around a sport stadium. A rapid transition then occurs, and the fish become highly polarised and synchronized in the manner of schooling fish. After the transition, the schools start migrating, extending up to 40 kilometres (25 mi) across the ocean, to shallow parts of the bank. There they spawn during the night. In the morning, the fish school back to deeper water again and then disband. Small groups of leaders were also discovered that significantly influenced much larger groups.

Making decisions

Fish schools are faced with decisions they must make if they are to remain together. For example, a decision might be which direction to swim when confronted by a predator, which areas to stop and forage, or when and where to migrate. How are these decisions made? Do more experienced 'leaders' exert more influence than other group members, or does the group make a decision by consensus? A recent investigation showed that small groups of fish used consensus decision-making when deciding which fish model to follow. The fish did this by a simple quorum rule such that individuals watched the decisions of others before making their own decisions. This technique generally resulted in the 'correct' decision but occasionally cascaded into the 'incorrect' decision. In addition, as the group size increased, the fish made more accurate decisions in following the more attractive fish model. Consensus decision-making, a form of collective intelligence, thus effectively uses information from multiple sources to generally reach the correct conclusion.

Other open questions of shoaling behaviour include identifying which individuals are responsible for the direction of shoal movement. In the case of migratory movement, most members of a shoal seem to know where they are going. Observations on the foraging behaviour of captive golden shiner (a kind of minnow) found they formed shoals which were led by a small number of experienced individuals who knew when and where food was available. In a herd of sheep the same lead sheep are always in the front row. But in a school of migrating fish, if the school changes direction, the fish previously at the flank become the lead fish.

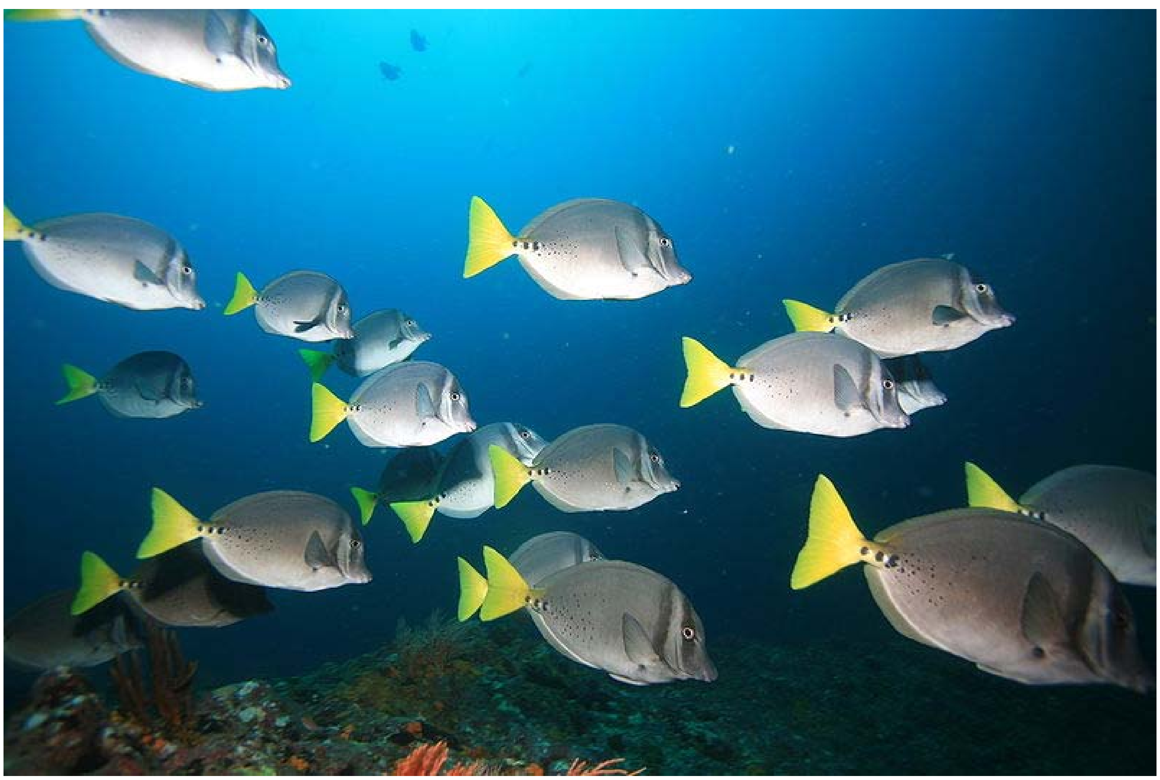
One puzzling aspect of shoal selection is how a fish can choose to join a shoal of animals similar to themselves, given that it cannot know its own appearance. Experiments with zebrafish have shown that shoal preference is a learned ability, not innate. A zebrafish tends to associate with shoals that resemble shoals in which it was reared (that is, a form of imprinting).

Shool of Silver moony at Madagascar

Passer Angelfish (Holocanthus passer)

A school of bar jacks in open water

A school of Golden Crevalle (Gnathanodon speciosus)



A school of Yellowtail Surgeonfish (Prionurus laticlavius)

Schooling yellowtail barracuda. Sphyraena flavicauda.

Barracuda

Commercial fishing

The schooling behaviour of fish is exploited on an industrial scale by the commercial fishing industry. Huge purse seiner vessels use spotter planes to locate schooling fish, such as tuna, cod, mackerel and forage fish. They can capture huge schools by rapidly encircling them with purse seine nets with the help of fast auxiliary boats and sophisticated sonar, which can track the shape of the shoal.

Further examples

School of blacksmiths being cleaned by parasite eating fish

Piranha are rather fearful fish, who school for protection from predators.

- Blacksmith fish live in loose shoals. They have a symbiotic relationship with the parasite eating senorita fish. When they encounter a shoal of senorita fish, they stop and form a tight ball and hang upside down (pictured), each fish waiting its turn to be cleaned. The senorita fish pick dead tissues and external parasites, like parasitic copecods and isocods, from the skin of other fishes.
- Subsets of bottlenose dolphin populations in Mauritania are known to engage in interspecific cooperative fishing with human fishermen. The dolphins drive a school of fish towards the shore where humans await with their nets. In the confusion of casting nets, the dolphins catch a large number of fish as well. Intraspecific cooperative foraging techniques have also been observed, and some propose that these behaviours are transmitted through cultural means. Rendell & Whitehead have proposed a structure for the study of culture in cetaceans,
- Some fish shoals engage in mobbing behaviour. For example, bluegills form large nesting colonies and sometimes attack snapping turtles. This may function to advertise their presence, drive the predator from the area, or aid in cultural transmission of predator recognition.
- Piranha have a reputation as fearless fish that hunt in ferocious packs. However, recent research, which "started off with the premise that they school as a means of cooperative hunting", discovered that they were in fact rather fearful fish, like other fish, who schooled for protection from their predators, such as cormorants, caimans and dolphins. Piranhas are "basically like regular fish with large teeth".
- Humboldt squid are large carnivorous marine invertebrates that move in schools of up to 1,200 individuals. They swim at speeds of up to 24 kilometres per hour (15 mph/13 kn) propelled by water ejected through a siphon and by two triangular fins. Their tentacles bear suckers lined with sharp teeth with which they grasp prey and drag it towards a large, sharp beak. During the day the Humboldt squid are mesopelagic fish, living at depths of 200 to 700 m (660 to 2,300 ft). Electronic tagging has shown that they also undergo diel vertical migrations which bring them closer to the surface from dusk to dawn. They hunt near the surface at night, taking advantage of the dark to use their keen vision to feed on more plentiful prey. The squid feed primarily on small fish, crustaceans, cephalopods, and copepod, and hunt for their prey in a cooperative fashion, the first observation of such behaviour in invertebrates. The Humboldt squid is also known to quickly devour larger prey when cooperatively hunting in groups. Humboldt squid are known for their speed in feasting on hooked fish, sharks, and squid, even from their own species and shoal, and have been known to attack fishermen and divers. Their colouring and aggressive reputation has earned them the nickname *diablos rojos* (red devils) from fishermen off the coast of Mexico as they flash red and white when struggling with the fishermen.
- Other collective nouns used for fish include a *draught* of fish, a *drift* of fish, or a *scale* of fish. Collective nouns used for fish species groups include a *grind* of blackfish, a *troubling* of goldfish, *glean* of herrings, *bind* or *run* of salmon, *shiver* of sharks, *fever* of stingrays, *taint* of tilapia, *hover* of trouts and *pod* of whales.

Chapter- 11

Fish Diseases and Parasites

This gizzard shad has VHS, a deadly infectious disease which causes bleeding. It afflicts over 50 species of freshwater and marine fish in the northern hemisphere.

Like humans and other animals, fish suffer from diseases and parasites. Fish defences against disease are specific and non-specific. Non-specific defences include skin and scales, as well as the mucus layer secreted by the epidermis that traps microorganisms and inhibits their growth. If pathogens breach these defences, fish can develop inflammatory responses that increase the flow of blood to infected areas and deliver white blood cells that attempt to destroy the pathogens.

Specific defences are specialised responses to particular pathogens recognised by the fish's body, that is immune responses. In recent years, vaccines have become widely used in aquaculture and ornamental fish, for example vaccines for furunculosis in farmed salmon and koi herpes virus in koi.

Some commercially important fish diseases are VHS, ich and whirling disease.

Disease

A veterinarian gives an injection to a goldfish

All fish carry pathogens and parasites. Usually this is at some cost to the fish. If the cost is sufficiently high, then the impacts can be characterised as a disease. However disease in fish is not understood well. What is known about fish disease often relates to aquaria fish, and more recently, to farmed fish.

Disease is a prime agent affecting fish mortality, especially when fish are young. Fish can limit the impacts of pathogens and parasites with behavioural or biochemical means, and such fish have reproductive advantages. Interacting factors result in low grade infection becoming fatal diseases. In particular, things that causes stress, such as natural droughts or pollution or predators, can precipitate outbreak of disease.

Disease can also be particularly problematic when pathogens and parasites carried by introduced species affect native species. An introduced species may find invading easier if potential predators and competitors have been decimated by disease.

Pathogens can cause fish diseases such as:

- viral disorders

- bacterial infections, such as *Pseudomonas fluorescens* leading to fin rot and fish dropsy
- fungal infections, such as saprolegnia
- mould infections, such as oomycete and saprolegnia

Parasites

Parasites in fish are a natural occurrence and common. Parasites can provide information about host population ecology. In fisheries biology, for example, parasite communities can be used to distinguish distinct populations of the same fish species co-inhabiting a region. Additionally, parasites possess a variety of specialized traits and life-history strategies that enable them to colonize hosts. Understanding these aspects of parasite ecology, of interest in their own right, can illuminate parasite-avoidance strategies employed by hosts

Usually parasites (and pathogens) need to avoid killing their hosts, since extinct hosts can mean extinct parasites. Evolutionary constraints may operate so parasites avoid killing their hosts, or the natural variability in host defensive strategies may suffice to keep host populations viable. Parasite infections can impair the courtship dance of male threespine sticklebacks. When that happens, the females reject them, suggesting a strong mechanism for the selection of parasite resistance."

However not all parasites want to keep their hosts alive, and there are parasites with multistage life cycles who go to some trouble to kill their host. For example, some tapeworms make some fish behave in such a way that a predatory bird can catch it. The predatory bird is the next host for the parasite in the next stage of its life cycle. Specifically, the tapeworm *Schistocephalus solidus* turns infected threespine stickleback white, and then makes them more buoyant so that they splash along at the surface of the water, becoming easy to see and easy to catch for a passing bird.

Other parasitic disorders, include *Gyrodactylus salaris*, *Ichthyophthirius multifiliis*, cryptocaryon, velvet disease, *Brooklynella hostilis*, Hole in the head, *Glugea*, *Ceratomyxa shasta*, *Kudoa thyrsites*, *Tetracapsuloides bryosalmonae*, *Cymothoa exigua*, leeches, nematode, flukes, *Platyhelminthes*, carp lice and salmon lice

Mass die offs

Some diseases result in mass die offs. One of the more bizarre and recently discovered diseases produces huge fish kills in shallow marine waters. It is caused by the ambush predator dinoflagellate *Pfiesteria piscicida*. When large numbers of fish, like shoaling forage fish, are in confined situations such as shallow bays, the excretions from the fish encourage this dinoflagellate, which is not normally toxic, to produce free-swimming zoospores. If the fish remain in the area, continuing to provide nourishment, then the zoospores start secreting a neurotoxin. This toxin results in the fish developing bleeding lesions, and their skin flakes off in the water. The dinoflagellates then eat the blood and flakes of tissue while the affected fish die. Fish kills by this dinoflagellate are common, and they may also have been responsible for kills in the past which were thought to have had other causes. Kills like these can be viewed as natural mechanisms for regulating the population of exceptionally abundant fish. The rate at which the kills occur increases as organically polluted land runoff increases.

Cleaner fish

Two cleaner wrasses, *Labroides phthirophagus*, servicing a goatfish, *Mulloidichthys flavolineatus*

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

More than 40 species of parasites may reside on the skin and internally of the ocean sunfish, motivating the fish to seek relief in a number of ways. In temperate regions, drifting kelp fields harbour cleaner wrasses and other fish which remove parasites from the skin of visiting sunfish. In the tropics, the *mola* will solicit cleaner help from reef fishes. By basking on its side at the surface, the sunfish also allows seabirds to feed on parasites from their skin. Sunfish have been reported to breach more than ten feet above the surface, possibly as another effort to dislodge parasites on the body.

Wild salmon

Henneguya salminicola, a protozoan parasite commonly found in the flesh of salmonids on the West Coast of Canada. Coho salmon

According to Canadian biologist Dorothy Kieser, protozoan parasite *Henneguya salminicola* is commonly found in the flesh of salmonids. It has been recorded in the field samples of salmon returning to the Queen Charlotte Islands. The fish responds by walling off the parasitic infection into a number of cysts that contain milky fluid. This fluid is an accumulation of a large number of parasites.

Henneguya and other parasites in the myxosporean group have a complex lifecycle where the salmon is one of two hosts. The fish releases the spores after spawning. In the *Henneguya* case, the spores enter a second host, most likely an invertebrate, in the spawning stream. When juvenile salmon out-migrate to the Pacific Ocean, the second host releases a stage infective to salmon. The parasite is then carried in the salmon until the next spawning cycle. The myxosporean parasite that causes whirling disease in trout, has a similar lifecycle. However, as opposed to whirling disease, the *Henneguya* infestation does not appear to cause disease in the host salmon — even heavily infected fish tend to return to spawn successfully.

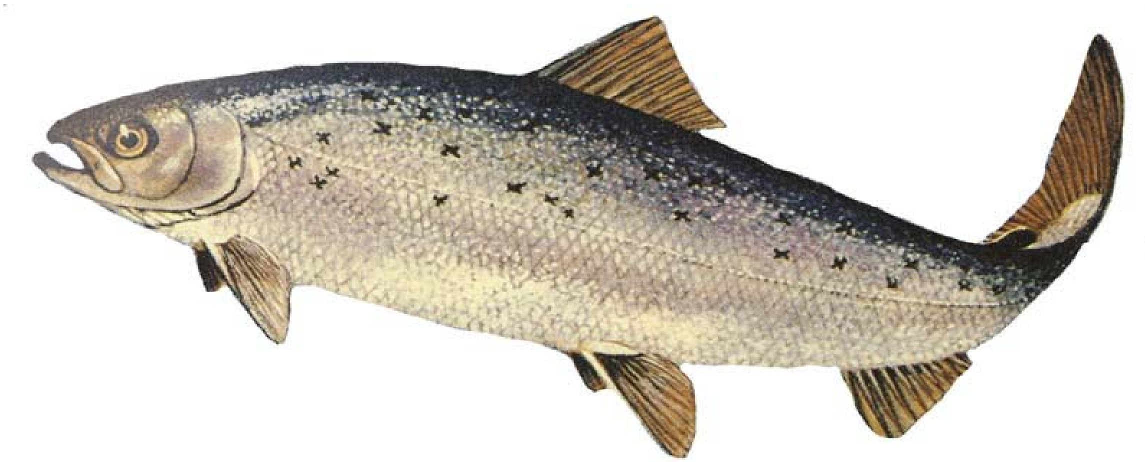
According to Dr. Kieser, a lot of work on *Henneguya salminicola* was done by scientists at the Pacific Biological Station in Nanaimo in the mid-1980s, in particular, an overview report which states that "the fish that have the longest fresh water residence time as juveniles have the most noticeable infections. Hence in order of prevalence coho are most infected followed by sockeye, chinook, chum and pink." As well, the report says that, at the time the studies were conducted, stocks from the middle and upper reaches of large river systems in British Columbia such as Fraser, Skeena, Nass and from mainland coastal streams in the southern half of B.C. "are more likely to have a low prevalence of infection." The report also states "It should be stressed that *Henneguya*, economically deleterious though it is, is harmless from the view of public health. It is strictly a fish parasite that cannot live in or affect warm blooded animals, including man".

Sample of pink salmon infected with Henneguya salminicola, caught off the Queen Charlotte Islands, Western Canada in 2009

According to Klaus Schallie, Molluscan Shellfish Program Specialist with the Canadian Food Inspection Agency, "*Henneguya salminicola* is found in southern B.C. also and in all species of salmon. I have previously examined smoked chum salmon sides that were riddled with cysts and some sockeye runs in Barkley Sound (southern B.C., west coast of Vancouver Island) are noted for their high incidence of infestation."

Sea lice, particularly *Lepeophtheirus salmonis* and a variety of *Caligus* species, including *Caligus clemensi* and *Caligus rogercresseyi*, can cause deadly infestations of both farm-grown and wild salmon. Sea lice are ectoparasites which feed on mucous, blood, and skin, and migrate and latch onto the skin of wild salmon during free-swimming, planktonic *naupli* and *copepodid* larval stages, which can persist for several days. Large numbers of highly populated, open-net salmon farms can create exceptionally large concentrations of sea lice; when exposed in river estuaries containing large numbers of open-net farms, many young wild salmon are infected, and do not survive as a result. Adult salmon may survive otherwise critical numbers of sea lice, but small, thin-skinned juvenile salmon migrating to sea are highly vulnerable. On the Pacific coast of Canada, the louse-induced mortality of pink salmon in some regions is commonly over 80%.

Farmed salmon

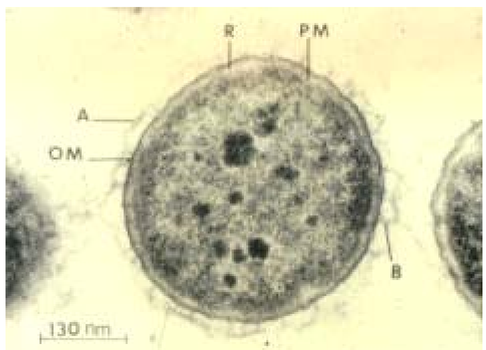


Atlantic salmon

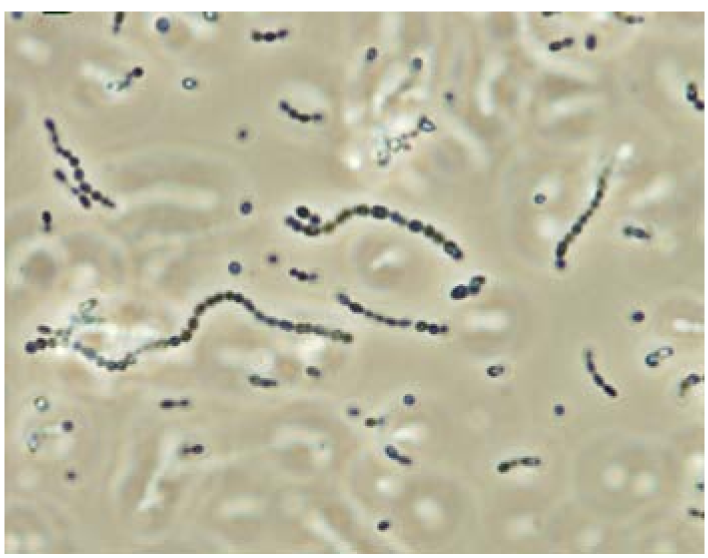
In 1972, Gyrodactylus, a monogenean parasite, spread from Norwegian hatcheries to wild salmon, and devastated some wild salmon populations.

In 1984, infectious salmon anemia (ISAv) was discovered in Norway in an Atlantic salmon hatchery. Eighty percent of the fish in the outbreak died. ISAv, a viral disease, is now a major threat to the viability of Atlantic salmon farming. It is now the first of the diseases classified on List One of the European Commission's fish health regime. Amongst other measures, this requires the total eradication of the entire fish stock should an outbreak of the disease be confirmed on any farm. ISAv seriously affects salmon farms in Chile, Norway, Scotland and Canada, causing major economic losses to infected farms. As the name implies, it causes severe anemia of infected fish. Unlike mammals, the red blood cells of fish have DNA, and can become infected with viruses. The fish develop pale gills, and may swim close to the water surface, gulping for air. However, the disease can also develop without the fish showing any external signs of illness, the fish maintain a normal appetite, and then they suddenly die. The disease can progress slowly throughout an infected farm and, in the worst cases, death rates may approach 100 percent. It is also a threat to the dwindling stocks of wild salmon. Management strategies include developing a vaccine and improving genetic resistance to the disease.

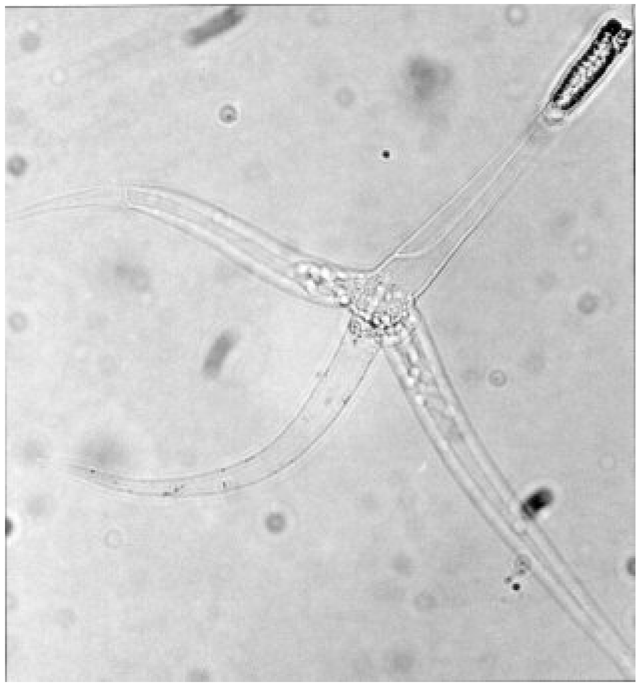
In the wild, diseases and parasites are normally at low levels, and kept in check by natural predation on weakened individuals. In crowded net pens they can become epidemics. Diseases and parasites also transfer from farmed to wild salmon populations. A recent study in British Columbia links the spread of parasitic sea lice from river salmon farms to wild pink salmon in the same river." The European Commission (2002) concluded "The reduction of wild salmonid abundance is also linked to other factors but there is more and more scientific evidence establishing a direct link between the number of lice-infested wild fish and the presence of cages in the same estuary." It is reported that wild salmon on the west coast of Canada are being driven to extinction by sea lice from nearby salmon farms. Antibiotics and pesticides are often used to control the diseases and parasites.



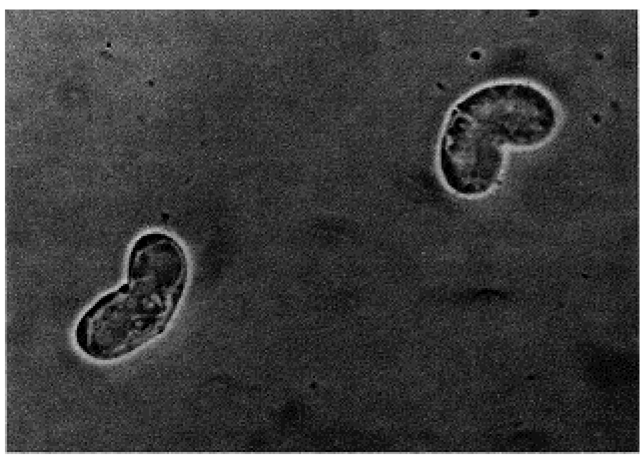
Aeromonas salmonicida, a Gram-negative bacteria, causes the disease furunculosis in marine and freshwater fish.



Streptococcus iniae, a Gram-positive, sphere-shaped bacteria caused losses in farmed marine and freshwater finfish of US$100 million in 1997.

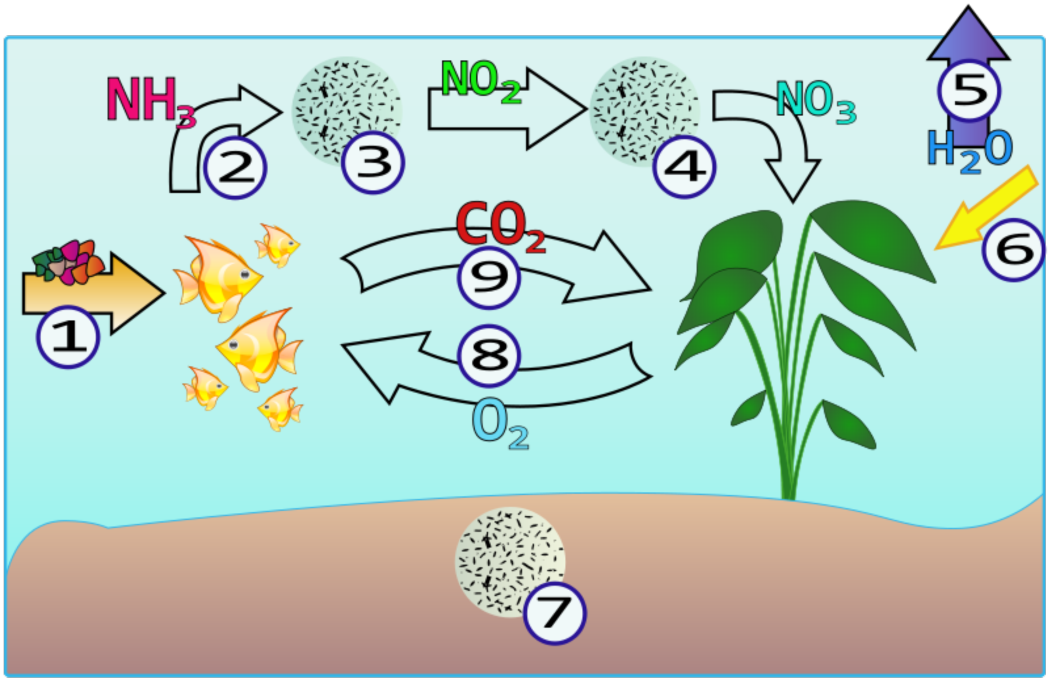


Myxobolus cerebralis, a myxosporean parasite, causes *whirling disease* in farmed salmon and trout and also in wild fish populations.



Ceratomyxa shasta, another myxosporean parasite, infects salmonid fish on the Pacific coast of North America.

Aquarium fish



Nitrogen cycle in a common aquarium

Ornamental fish kept in aquariums are susceptible to numerous diseases.

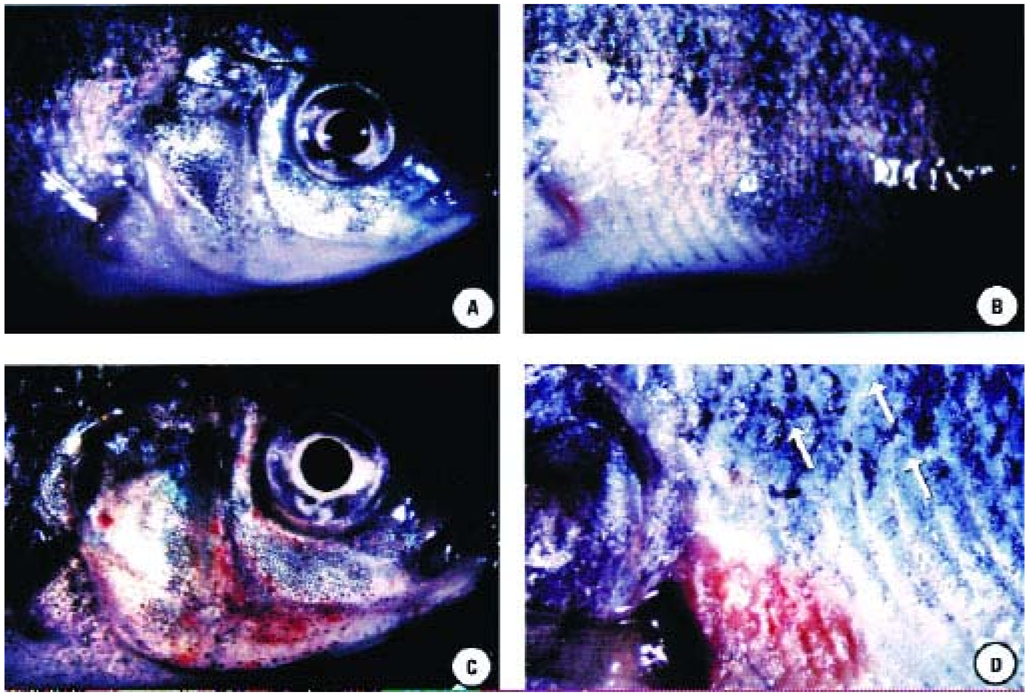
In most aquarium tanks, the fish are at high concentrations and the volume of water is limited. This means that communicable diseases can spread rapidly to most or all fish in a tank. An improper nitrogen cycle, inappropriate aquarium plants and potentially harmful freshwater invertebrates can directly harm or add to the stresses on ornamental fish in a tank. Despite this, many diseases in captive fish can be avoided or prevented through proper water conditions and a well-adjusted ecosystem within the tank. Ammonia poisoning is a common disease in new aquariums, especially when immediately stocked to full capacity.

Due to their generally small size and the low cost of replacing diseased or dead aquarium fish, the cost of testing and treating diseases is often seen as more trouble than the value of the fish.

Goldfish with dropsy

Columnaris in the gill of a chinook salmon

The parasite *Henneguya zschokkei* in salmon beard

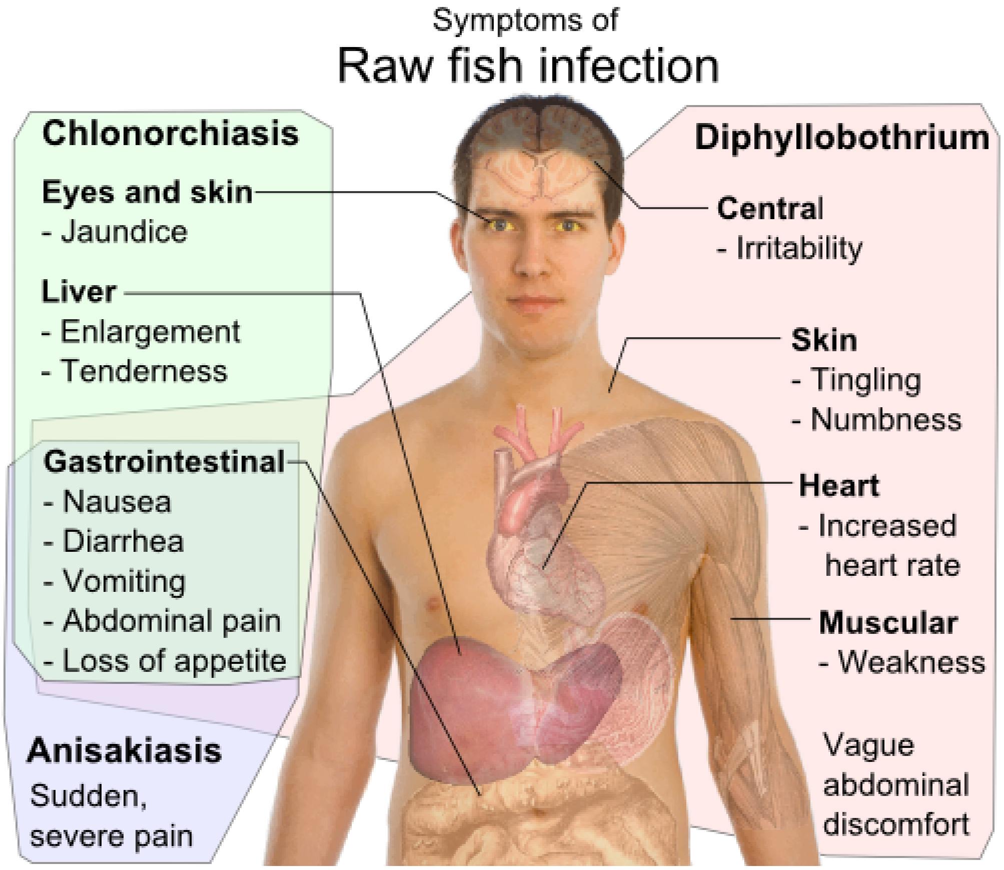


Skin ulcers in tilapia exposed to Pfiesteria shumwayae

Spreading disease and parasites

The capture, transportation and culture of bait fish can spread damaging organisms between ecosystems, endangering them. In 2007, several American states, including Michigan, enacted regulations designed to slow the spread of fish diseases, including viral hemorrhagic septicemia, by bait fish. Because of the risk of transmitting *Myxobolus cerebralis* (whirling disease), trout and salmon should not be used as bait. Anglers may increase the possibility of contamination by emptying bait buckets into fishing venues and collecting or using bait improperly. The transportation of fish from one location to another can break the law and cause the introduction of fish and parasites alien to the ecosystem.

Eating raw fish



Differential symptoms of parasite infection by raw fish: Clonorchis sinensis (a trematode/fluke), Anisakis (a nematode/roundworm) and Diphyllobothrium a (cestode/tapeworm), all have gastrointestinal, but otherwise distinct, symptoms.

Though not a health concern in thoroughly cooked fish, parasites are a concern when human consumers eat raw or lightly preserved fish such as sashimi, sushi, ceviche, and gravlax. The popularity of such raw fish dishes makes it important for consumers to be aware of this risk. Raw fish should be frozen to an internal temperature of −20°C (−4°F) for at least 7 days to kill parasites. It is important to be aware that home freezers may not be cold enough to kill parasites.

Traditionally, fish that live all or part of their lives in fresh water were considered unsuitable for sashimi due to the possibility of parasites. Parasitic infections from freshwater fish are a serious problem in some parts of the world, particularly Southeast Asia. Fish that spend part of their life cycle in brackish or freshwater, like salmon are a particular problem. A study in Seattle, Washington showed that 100% of wild salmon had roundworm larvae capable of infecting people. In the same study farm raised salmon did not have any roundworm larvae.

Parasite infection by raw fish is rare in the developed world (fewer than 40 cases per year in the U.S.), and involves mainly three kinds of parasites: Clonorchis sinensis (a trematode/fluke), Anisakis (a nematode/roundworm) and Diphyllobothrium (a cestode/tapeworm). Infection risk of anisakis is particularly higher in fishes which may live in a river such as salmon (*shake*) in Salmonidae, mackerel (*saba*). Such parasite infections can generally be avoided by boiling, burning, preserving in salt or vinegar, or freezing overnight. Even Japanese people never eat raw salmon and ikura, and even if they seem raw, these foods are not raw but are frozen overnight to prevent infections from parasites, particularly anisakis.