



Fish

(aquatic vertebrate animal)

Otha Faust

First Edition, 2012

ISBN 978-81-323-3146-9

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Published by:

Research World

4735/22 Prakashdeep Bldg,

Ansari Road, Darya Ganj,

Delhi - 110002

Email: info@wtbooks.com

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Chapter- 1

Fish

Fish

Fossil range: Ordovician–Neogene



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



The ornate lionfish as seen from a head-on view

Scientific classification

Kingdom: Animalia

Phylum: Chordata

(unranked) Craniata

Included groups

Jawless fish

†Armoured fish

Cartilaginous fish

Ray-finned fish

Lobe-finned fishes

Excluded groups

Tetrapods

A **fish** is any aquatic vertebrate animal that is covered with scales, and equipped with two sets of paired fins and several unpaired fins. Most fish are "cold-blooded", or ectothermic, allowing their body temperatures to vary as ambient temperatures change. Fish are abundant in most bodies of water. They can be found in nearly all aquatic environments, from high mountain streams (e.g., char and gudgeon) to the abyssal and even hadal depths of the deepest oceans (e.g., gulpers and anglerfish). At 31,900 species, fish exhibit greater species diversity than any other class of vertebrates.

Food prepared from animals classified as fish is also referred to as fish, and is an important human food source. Commercial and subsistence fishers hunt fish in wild fisheries or farm them in ponds or in cages in the ocean. They are also caught by recreational fishers and raised by fishkeepers, and are exhibited in public aquaria. Fish have had a role in culture through the ages, serving as deities, religious symbols, and as the subjects of art, books and movies.

Diversity of fish

The term "fish" most precisely describes any non-tetrapod craniate (i.e. an animal with a skull and in most cases a backbone) that has gills throughout life and whose limbs, if any, are 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 hagfishes, lampreys, sharks and rays, ray-finned fish, coelacanths, and lungfish. Indeed, lungfish and coelacanths are closer relatives of tetrapods (such as mammals, birds, amphibians, etc.) than of other fish such as ray-finned fish or sharks, so the last common ancestor of all fish is also an ancestor to tetrapods. As paraphyletic groups are no longer recognised in modern systematic biology, the use of the term "fish" as a biological group must be avoided.

Many types of aquatic animals commonly referred to as "fish" are not fish in the sense given above; examples include shellfish, cuttlefish, starfish, crayfish and jellyfish. In earlier times, even biologists did not make a distinction – sixteenth century natural historians classified also seals, whales, amphibians, crocodiles, even hippopotamuses, as well as a host of aquatic invertebrates, as fish. However, according the definition above, all mammals, including Cetaceans like Whales and Dolphins, are not fish. In some contexts, especially in aquaculture, the true fish are referred to as **finfish** (or **fin fish**) to distinguish them from these other animals.

A typical fish is ectothermic, has a streamlined body for rapid swimming, extracts oxygen from water using gills or uses an accessory breathing organ to breathe atmospheric oxygen, has two sets of paired fins, usually one or two (rarely three) dorsal fins, an anal fin, and a tail fin, has jaws, has skin that is usually covered with scales, and lays eggs.



Fish come in many shapes and sizes. This is a sea dragon, a close relative of the seahorse. Their leaf-like appendages enable them to blend in with floating seaweed.

Each criterion has exceptions. Tuna, swordfish, and some species of sharks show some warm-blooded adaptations—they can heat their bodies significantly above ambient water temperature. Streamlining and swimming performance varies from fish such as tuna, salmon, and jacks that can cover 10–20 body-lengths per second to species such as eels and rays that swim no more than 0.5 body-lengths per second. Many groups of freshwater fish extract oxygen from the air as well as from the water using a variety of different structures. Lungfish have paired lungs similar to those of tetrapods, gouramis have a structure called the labyrinth organ that performs a similar function, while many catfish, such as *Corydoras* extract oxygen via the intestine or stomach. Body shape and the arrangement of the fins is highly variable, covering such seemingly un-fishlike forms as seahorses, pufferfish, anglerfish, and gulpers. Similarly, the surface of the skin may be naked (as in moray eels), or covered with scales of a variety of different types usually defined as placoid (typical of sharks and rays), cosmoid (fossil lungfish and coelacanths), ganoid (various fossil fish but also living gars and bichirs), cycloid, and ctenoid (these last two are found on most bony fish). There are even fish that live mostly on land. Mudskippers feed and interact with one another on mudflats and go underwater to hide in their burrows. The catfish *Phreatobius cisternarum* lives in underground, phreatic habitats, and a relative lives in waterlogged leaf litter.

Fish range in size from the huge 16-metre (52 ft) whale shark to the tiny 8-millimetre (0.3 in) stout infantfish.

Taxonomy

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

Fish are classified into the following major groups:

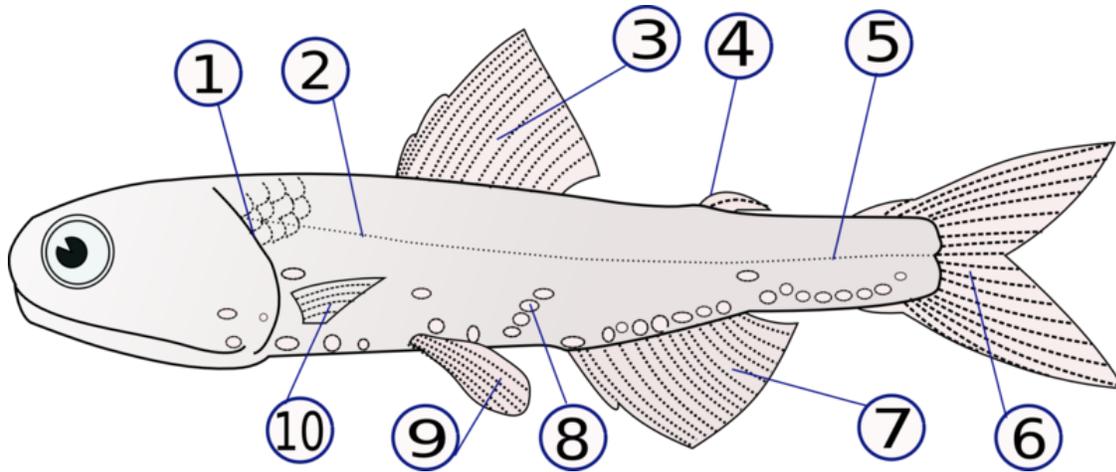
- Class Myxini (hagfish)
- Class Pteraspidomorphi (early jawless fish)
- Class Thelodonti
- Class Anaspida
- Class Petromyzontida or Hyperoartia
 - Petromyzontidae (lampreys)
- Class Conodonta (conodonts)
- Class Cephalaspidomorphi (early jawless fish)
 - (unranked) Galeaspida
 - (unranked) Pituriaspida
 - (unranked) Osteostraci
- Infraphylum Gnathostomata (jawed vertebrates)
 - Class Placodermi (armoured fish, extinct)
 - Class Chondrichthyes (cartilaginous fish)
 - Class Acanthodii (spiny sharks, extinct)
 - Superclass Osteichthyes (bony fish)
 - Class Actinopterygii (ray-finned fish)
 - Subclass Chondrostei
 - Order Acipenseriformes (sturgeons and paddlefishes)
 - Order Polypteriformes (reedfishes and bichirs).
 - Subclass Neopterygii
 - Infraclass Holostei (gars and bowfins)
 - Infraclass Teleostei (many orders of common fish)
 - Class Sarcopterygii (lobe-finned fish)
 - Subclass Coelacanthimorpha (coelacanths)
 - Subclass Dipnoi (lungfish)

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

The position of hagfish in the phylum chordata is not settled. Phylogenetic research in 1998 and 1999 supported the idea that the hagfish and the lampreys form a natural group, the Cyclostomata, that is a sister group of the Gnathostomata.

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

Anatomy



The anatomy of *Lampanyctodes hectoris*

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

Respiration

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

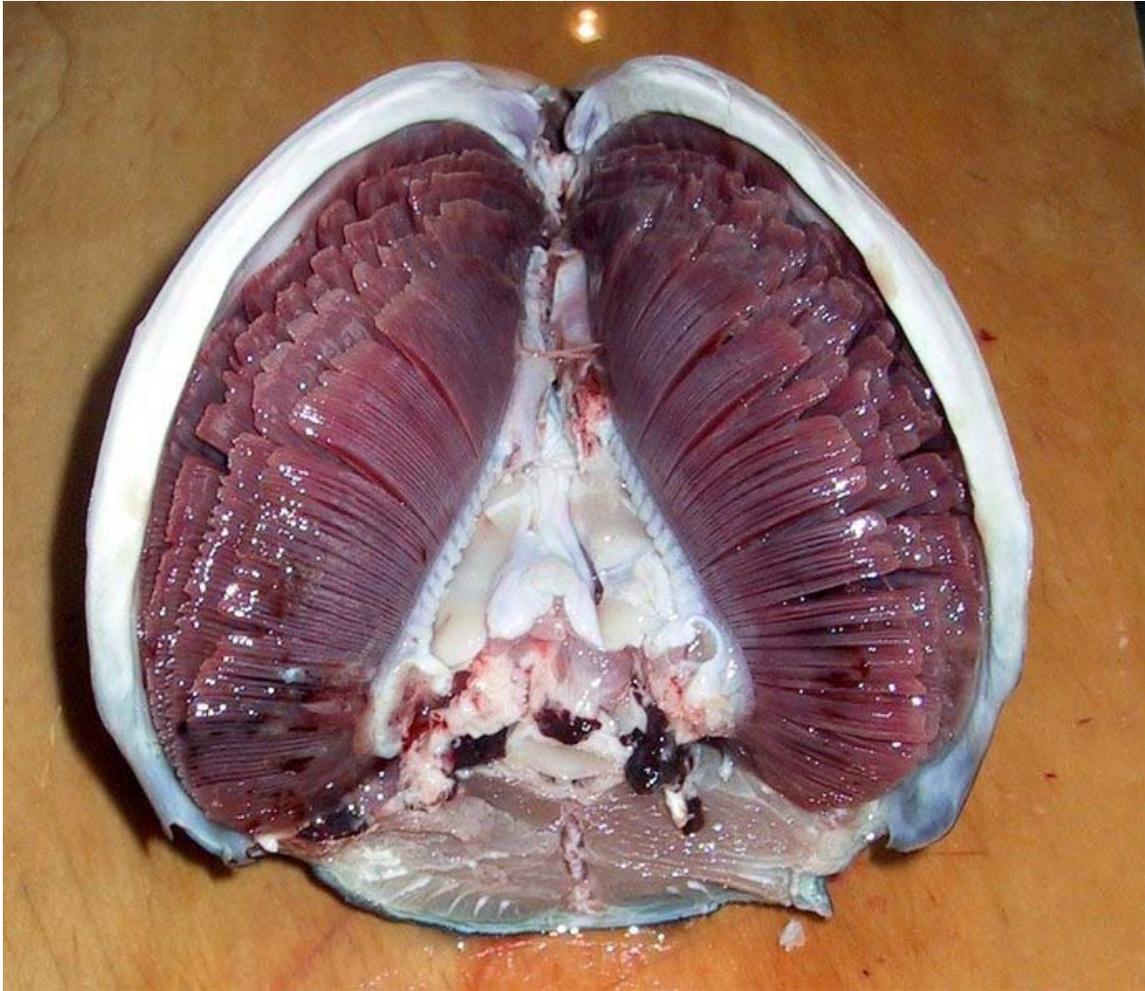
Juvenile bichirs have external gills, a very primitive feature that they share with larval amphibians.



Swim bladder of a Rudd (*Scardinius erythrophthalmus*)

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

Breathing air is primarily of use to fish that inhabit shallow, seasonally variable waters where the water's oxygen concentration may seasonally decline. Fish dependent solely on dissolved oxygen, such as perch and cichlids, quickly suffocate, while air-breathers survive for much longer, in some cases in water that is little more than wet mud. At the most extreme, some air-breathing fish are able to survive in damp burrows for weeks without water, entering a state of aestivation (summertime hibernation) until water returns.



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

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

Circulation

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

chamber and it pumps the blood, first to the fourth part, bulbous arteriosus, a large tube, and then out of the heart. The bulbus arteriosus connects to the aorta, through which blood flows to the gills for oxygenation.

Digestion

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

Excretion

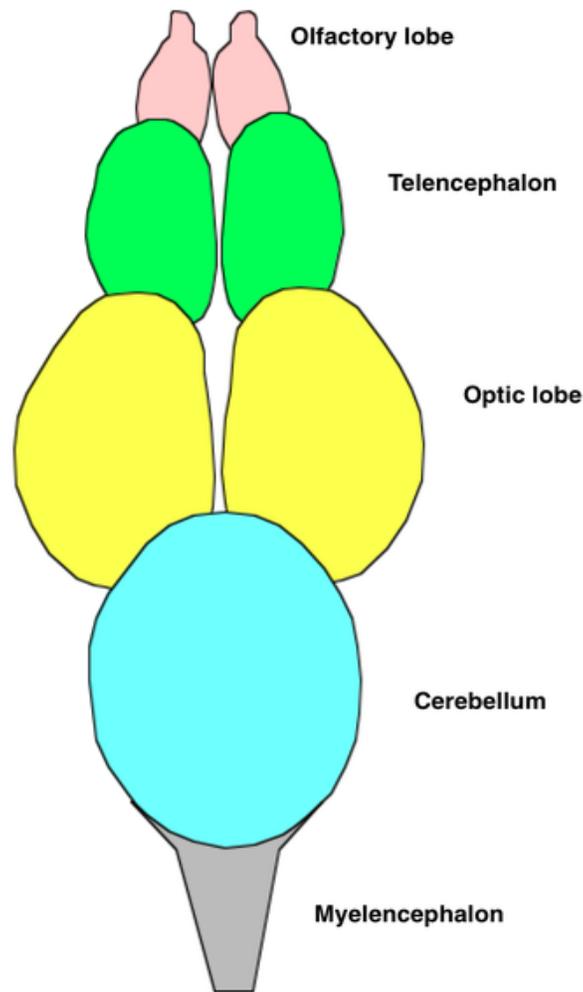
As with many aquatic animals, most fish release their nitrogenous wastes as ammonia. Some of the wastes diffuse through the gills. Blood wastes are filtered by the kidneys.

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

Scales

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

Sensory and nervous system



Dorsal view of the brain of the rainbow trout

Central nervous system

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

Fish brains are divided into several regions. At the front are the olfactory lobes, a pair of structures that receive and process signals from the nostrils via the two olfactory nerves. The olfactory lobes are very large in fish that hunt primarily by smell, such as hagfish, sharks, and catfish. Behind the olfactory lobes is the two-lobed telencephalon, the structural equivalent to the cerebrum in higher vertebrates. In fish the telencephalon is concerned mostly with olfaction. Together these structures form the **forebrain**.

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

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

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

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

Sense organs

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

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

Capacity for pain

Experiments done by William Tavalga provide evidence that fish have pain and fear responses. For instance, in Tavalga's experiments, toadfish grunted when electrically shocked and over time they came to grunt at the mere sight of an electrode.

In 2003, Scottish scientists at the University of Edinburgh and the Roslin Institute concluded that rainbow trout exhibit behaviors often associated with pain in other animals. Bee venom and acetic acid injected into the lips resulted in fish rocking their bodies and rubbing their lips along the sides and floors of their tanks, which the researchers concluded were attempts to relieve pain, similar to what mammals would do. Neurons fired in a pattern resembling human neuronal patterns.

Professor James D. Rose of the University of Wyoming claimed the study was flawed since it did not provide proof that fish possess "conscious awareness, particularly a kind of awareness that is meaningfully like ours". Rose argues that since fish brains are so different from human brains, fish are probably not conscious in the manner humans are, so that reactions similar to human reactions to pain instead have other causes. Rose had published a study a year earlier arguing that fish cannot feel pain because their brains lack a neocortex. However, animal behaviorist Temple Grandin argues that fish could still have consciousness without a neocortex because "different species can use different brain structures and systems to handle the same functions."

Animal welfare advocates raise concerns about the possible suffering of fish caused by angling. Some countries, such as Germany have banned specific types of fishing, and the British RSPCA now formally prosecutes individuals who are cruel to fish.

Muscular system

Most fish move by alternately contracting paired sets of muscles on either side of the backbone. These contractions form S-shaped curves that move down the body. As each curve reaches the back fin, backward force is applied to the water, and in conjunction with the fins, moves the fish forward. The fish's fins function like an airplane's flaps. Fins also increase the tail's surface area, increasing speed. The streamlined body of the fish decreases the amount of friction from the water. Since body tissue is denser than water, fish must compensate for the difference or they will sink. Many bony fish have an internal organ called a swim bladder that adjusts their buoyancy through manipulation of gases.

Homeothermy



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

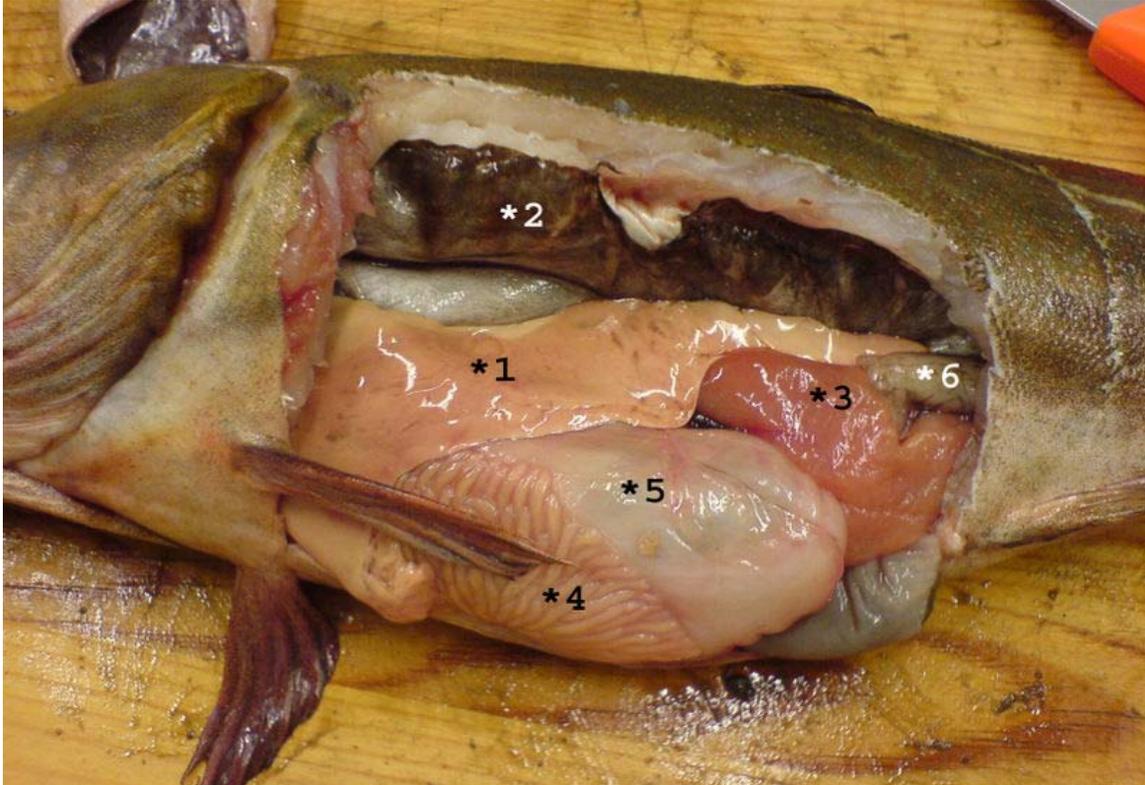
Although most fish are exclusively aquatic and ectothermic, there are exceptions to both cases.

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

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

Reproductive system

Organs



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

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

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

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

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

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

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

Reproductive method

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

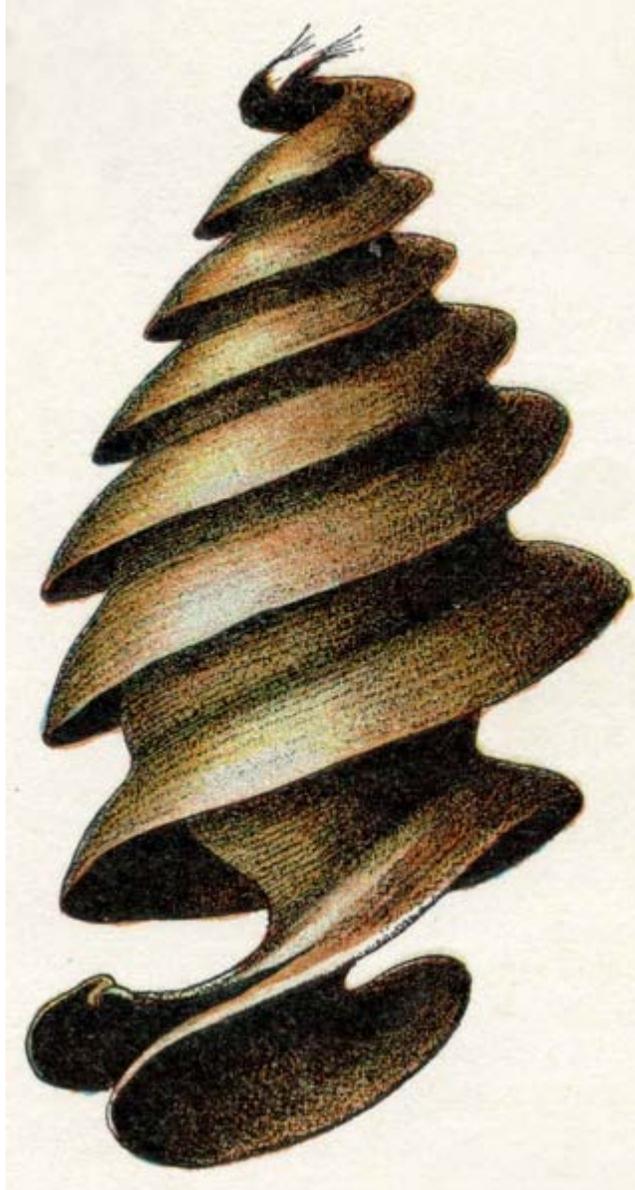
Marine fish can produce high numbers of eggs which are often released into the open water column. The eggs have an average diameter of 1 millimetre (0.039 in).



Egg of lamprey



Egg of catshark (mermaids' purse)



Egg of bullhead shark



Egg of chimaera

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

In ovoviviparous fish the eggs develop inside the mother's body after internal fertilization but receive little or no nourishment directly from the mother, depending instead on the

yolk. Each embryo develops in its own egg. Familiar examples of ovoviviparous fish include guppies, angel sharks, and coelacanth.

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

Aquarists commonly refer to ovoviviparous and viviparous fish as livebearers.

Immune system

Immune organs vary by type of fish. In the jawless fish (lampreys and hagfish), true lymphoid organs are absent. These fish rely on regions of lymphoid tissue within other organs to produce immune cells. For example, erythrocytes, macrophages and plasma cells are produced in the anterior kidney (or pronephros) and some areas of the gut (where granulocytes mature.) They resemble primitive bone marrow in hagfish. Cartilaginous fish (sharks and rays) have a more advanced immune system. They have three specialized organs that are unique to chondrichthyes; the epigonal organs (lymphoid tissue similar to mammalian bone) that surround the gonads, the Leydig's organ within the walls of their esophagus, and a spiral valve in their intestine. These organs house typical immune cells (granulocytes, lymphocytes and plasma cells). They also possess an identifiable thymus and a well-developed spleen (their most important immune organ) where various lymphocytes, plasma cells and macrophages develop and are stored. Chondrosteian fish (sturgeons, paddlefish and bichirs) possess a major site for the production of granulocytes within a mass that is associated with the meninges (membranes surrounding the central nervous system.) Their heart is frequently covered with tissue that contains lymphocytes, reticular cells and a small number of macrophages. The chondrosteian kidney is an important hemopoietic organ; where erythrocytes, granulocytes, lymphocytes and macrophages develop.

Like chondrosteian fish, the major immune tissues of bony fish (or teleostei) include the kidney (especially the anterior kidney), which houses many different immune cells. In addition, teleost fish possess a thymus, spleen and scattered immune areas within mucosal tissues (e.g. in the skin, gills, gut and gonads). Much like the mammalian immune system, teleost erythrocytes, neutrophils and granulocytes are believed to reside in the spleen whereas lymphocytes are the major cell type found in the thymus. In 2006, a lymphatic system similar to that in mammals was described in one species of teleost fish,

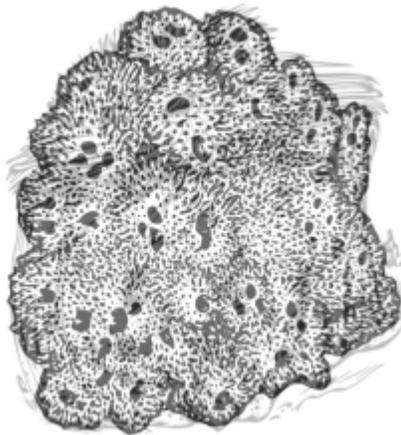
the zebrafish. Although not confirmed as yet, this system presumably will be where naive (unstimulated) T cells accumulate while waiting to encounter an antigen.

Diseases

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

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

Evolution



Outdated evolutionary view of continual gradation



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

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

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

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

Conservation



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

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

Overfishing

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

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

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

Habitat destruction

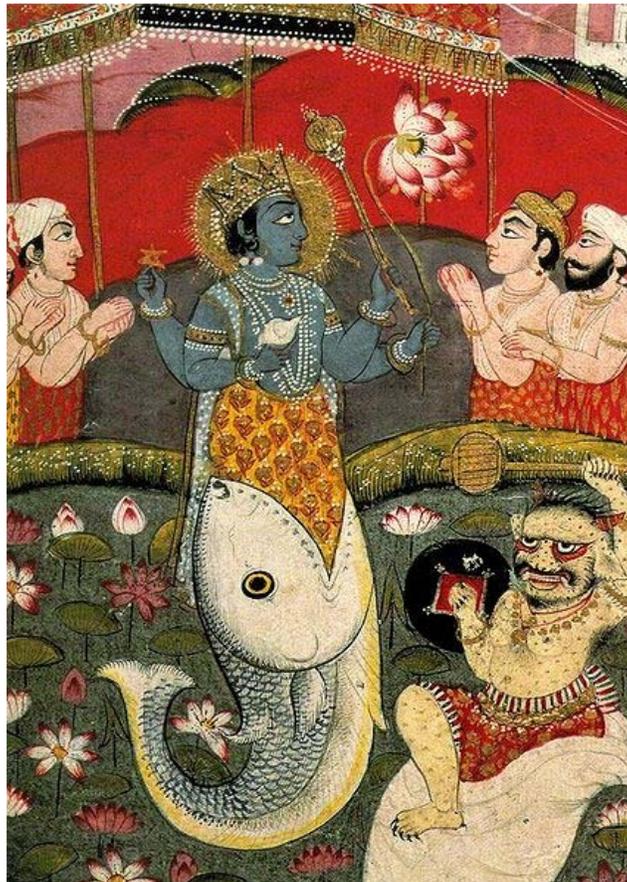
A key stress on both freshwater and marine ecosystems is habitat degradation including water pollution, the building of dams, removal of water for use by humans, and the introduction of exotic species. An example of a fish that has become endangered because of habitat change is the pallid sturgeon, a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

Exotic species

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

Aquarium collecting

Culture



Incarnation of Vishnu as a Merman

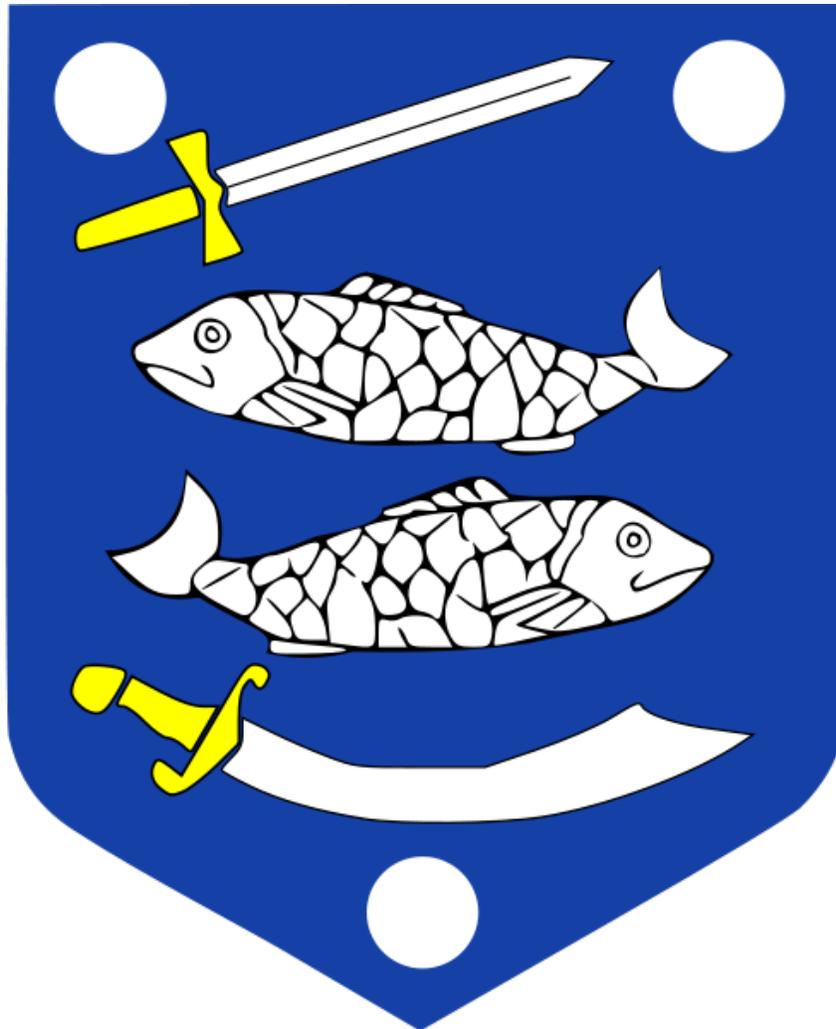
In the Book of Jonah a "great fish" swallowed Jonah the Prophet. Legends of half-human, half-fish mermaids have featured in stories like those of Hans Christian Andersen and movies like *Splash*.

Among the deities said to take the form of a fish are Ika-Roa of the Polynesians, Dagon of various ancient Semitic peoples, the shark-gods of Hawai'i and Matsya of the Dravidas of India. The astrological symbol Pisces is based on a constellation of the same name, but there is also a second fish constellation in the night sky, Piscis Austrinus.

Fish have been used figuratively in many different ways, for example the ichthys used by early Christians to identify themselves, through to the fish as a symbol of fertility among Bengalis.



Coat of arms of Comacchio, Italy



coat of arms of Narva, Estonia

Fish feature prominently in art and literature, in movies such as *Finding Nemo* and books such as *The Old Man and the Sea*. Large fish, particularly sharks, have frequently been the subject of horror movies and thrillers, most notably the novel *Jaws*, which spawned a series of films of the same name that in turn inspired similar films or parodies such as *Shark Tale*, *Snakehead Terror*, and *Piranha*.

In the semiotic of Ashtamangala (buddhist symbolism) the golden fish (Sanskrit: Matsya), represents the state of fearless suspension in samsara, perceived as the harmless ocean, referred to as 'buddha-eyes' or 'rigpa-sight'. The fish symbolizes the auspiciousness of all living beings in a state of fearlessness without danger of drowning in the Samsaric Ocean of Suffering, and migrating from teaching to teaching freely and spontaneously just as fish swim.



Fish riders in a 1920s poster of the Republic of China.

They have religious significance in Hindu, Jain and Buddhist traditions but also in Christianity who is first signified by the sign of the fish, and especially referring to feeding the multitude in the desert. In the dhamma of Buddha the fish symbolize happiness as they have complete freedom of movement in the water. They represent fertility and abundance. Often drawn in the form of carp which are regarded in the Orient as sacred on account of their elegant beauty, size and life-span.

The name of the Canadian city of Coquitlam, British Columbia is derived from *Kwikwetlem*, which is said to be derived from a Coast Salish term meaning "little red fish".

Terminology

Fish or fishes?

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

Shoal or school



These goldband fusiliers are schooling because their swimming is synchronised

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

Examples:

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

While school and shoal have different meanings within biology, they are often treated as synonyms by non-specialists, with speakers of British English using "shoal" to describe

any grouping of fish, while speakers of American English often using "school" just as loosely.

Chapter- 2

Fish Locomotion

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

Swimming

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

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

Body/caudal fin propulsion

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

Anguilliform locomotion

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

Sub-carangiform locomotion

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

Carangiform locomotion

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

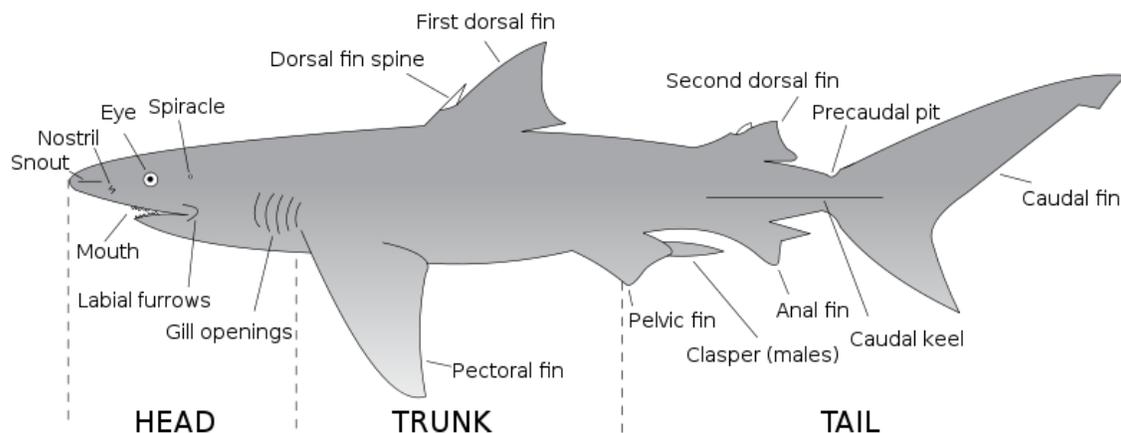
Thunniform locomotion

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

Median/paired fin propulsion

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

Dynamic lift



Bone and muscle tissues of fish are denser than water. To maintain depth some fish increase buoyancy by means of a gas bladder or by storing oils or lipids. Fish without

these features use dynamic lift instead. It is done using their pectoral fins in a manner similar to the use of wings by aeroplanes and birds. As these fish swim, their pectoral fins are positioned to create lift which allows the fish to maintain a certain depth.

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

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

Burrowing

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

Chapter- 3

Fish Diversity



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.

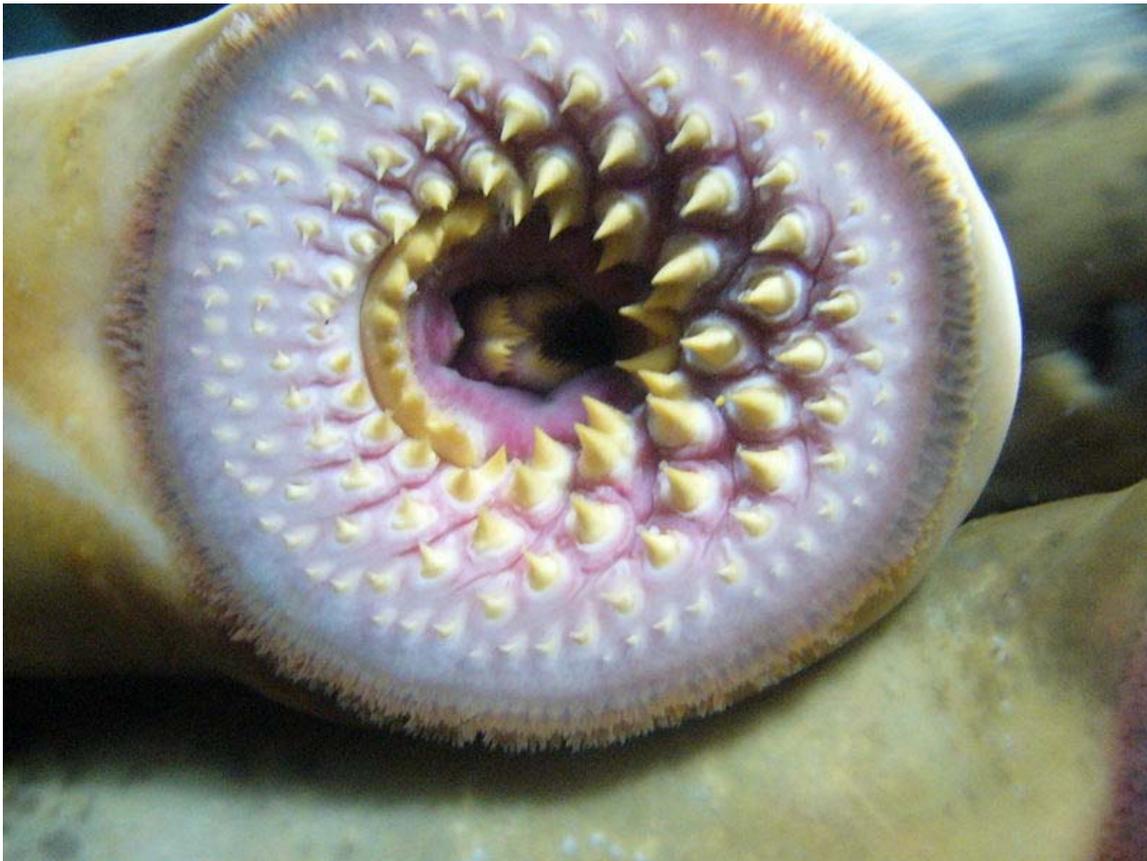
Jawless fish

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.



Lampreys attached to a lake trout



Mouth of a sea lamprey



Pacific hagfish resting on bottom at 280 m

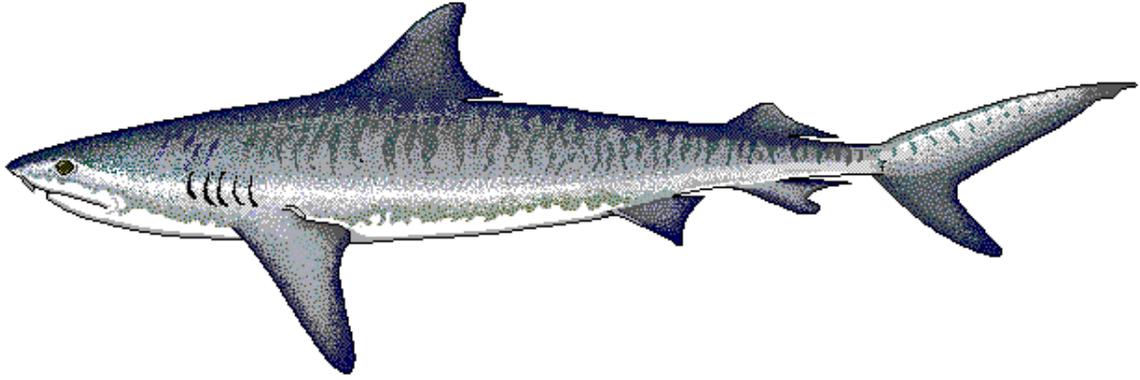


Stir-fried hagfish, from Korean cuisine

Cartilaginous fish

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

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



Tiger shark



Whale shark

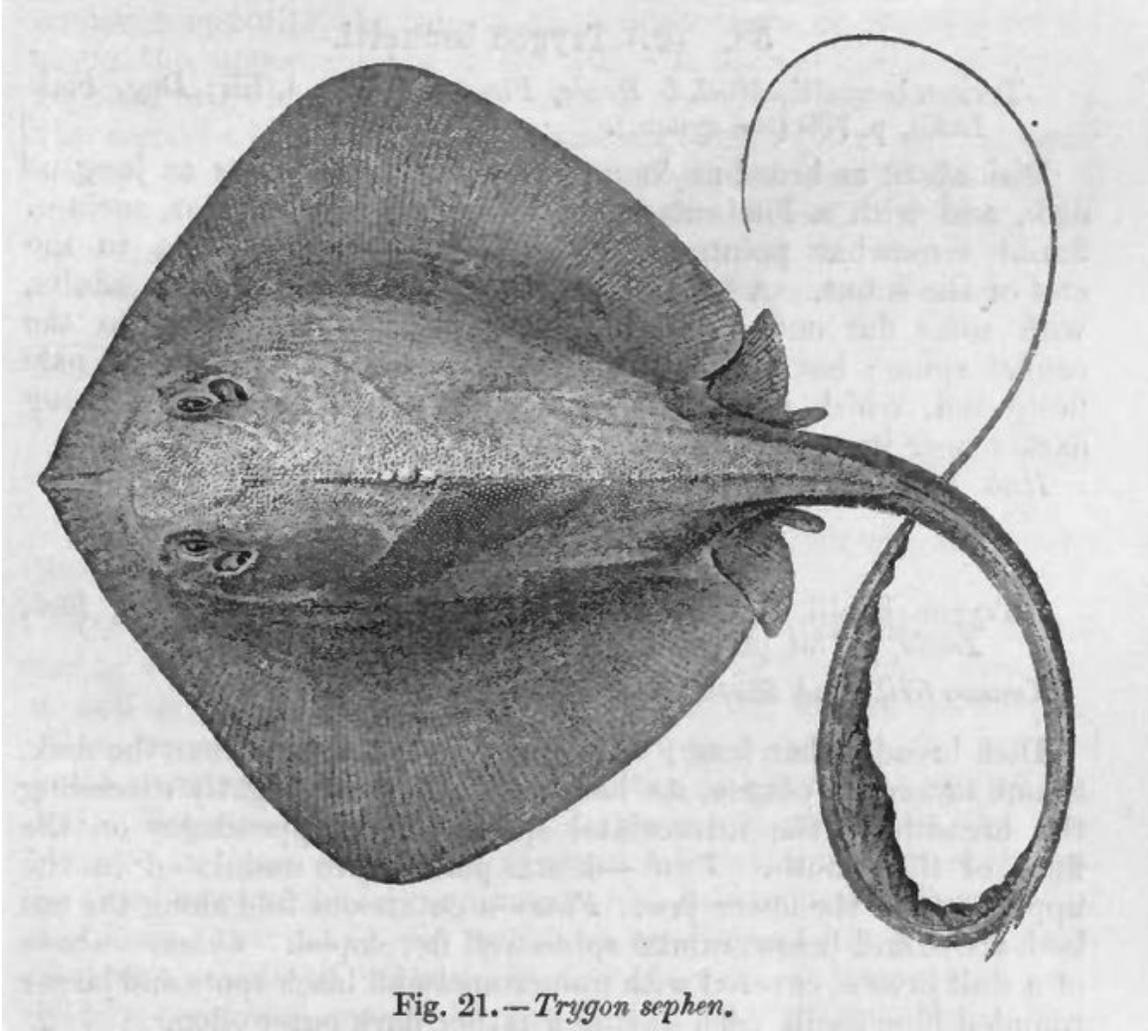
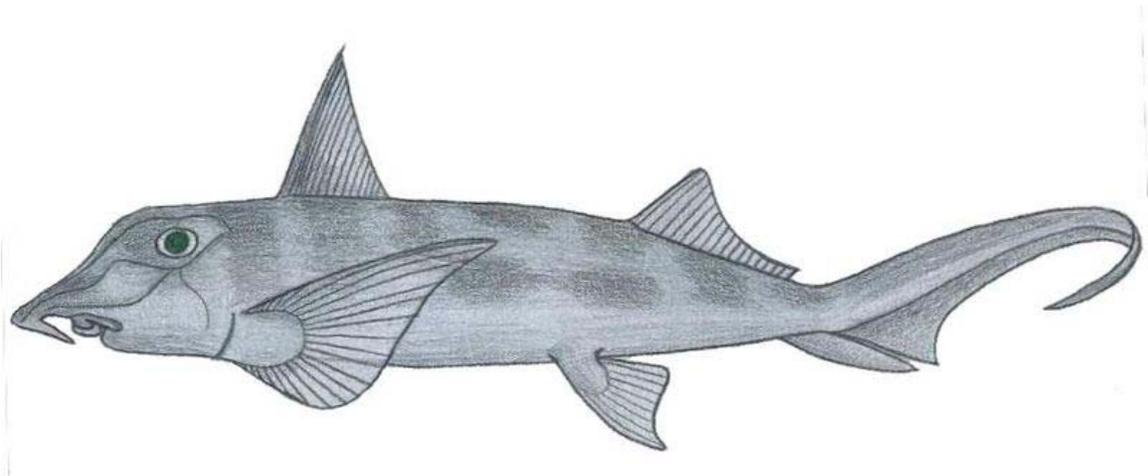


Fig. 21.—*Trygon sephen*.

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.



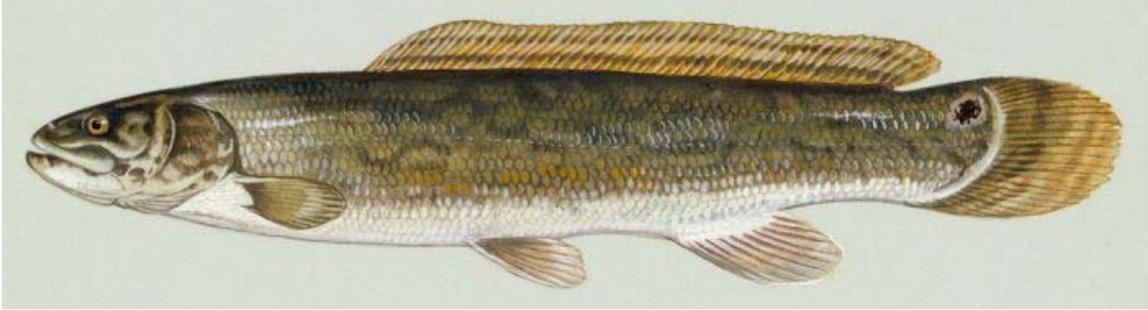
Lungfish can breathe in air as well as water



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



This Atlantic sturgeon is a chondrosteian



This bowfin is a holostean

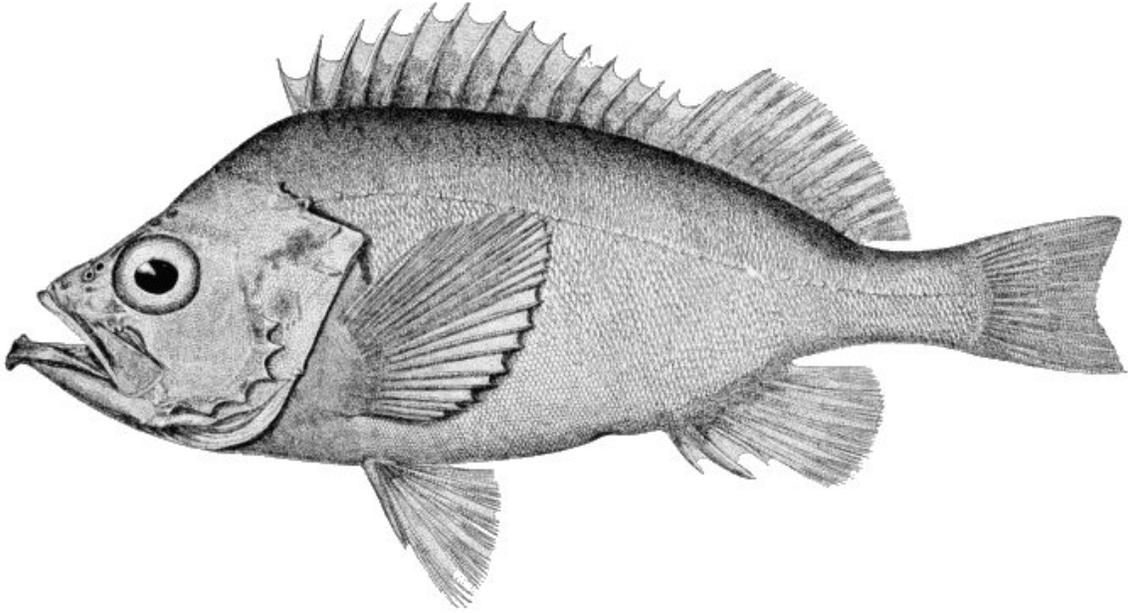
Teleosts

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.

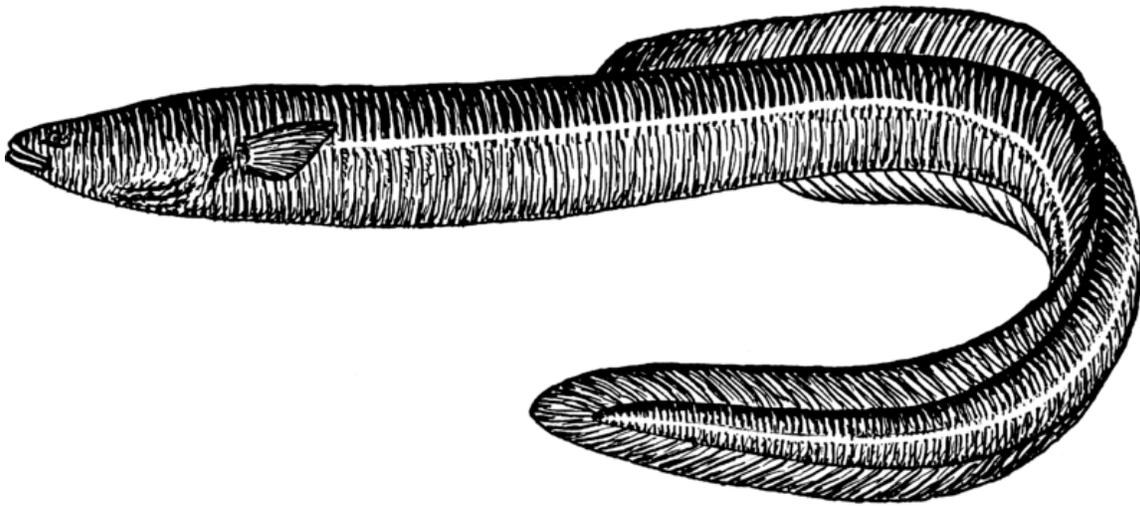
Teleosts have a movable maxilla and premaxilla and corresponding modifications in the jaw musculature. These modifications make it possible for teleosts to protrude their jaws outwards from the mouth. The caudal fin is homocercal, meaning the upper and lower lobes are about equal in size. The spine ends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

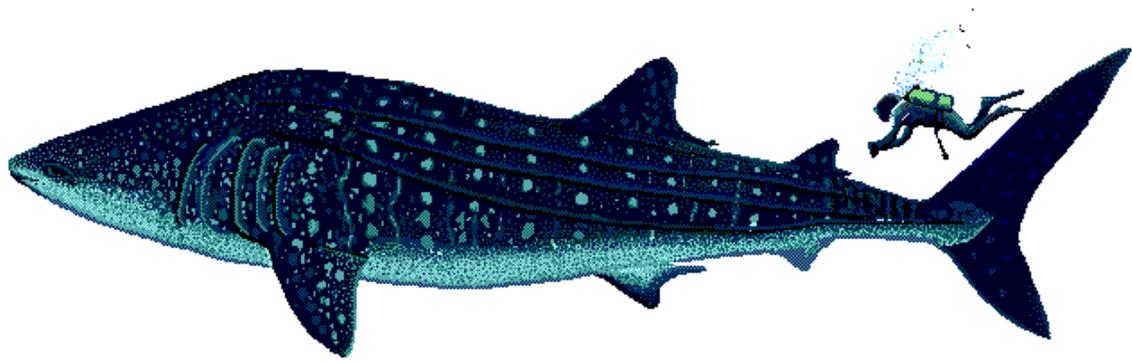
Found in the Philippines, they have an average length of 12.5 millimeters (0.5 in), and are threatened by overfishing.

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.

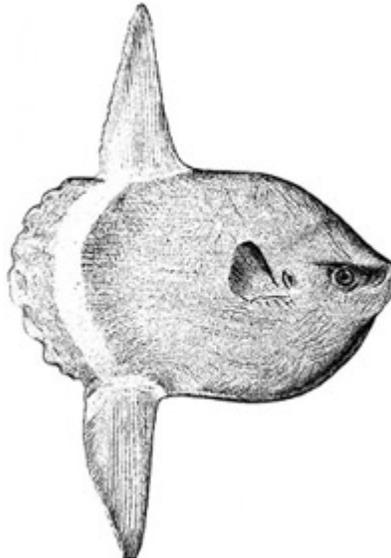
The heaviest bony fish is the ocean sunfish. It can weigh up to 2,300 kg (5,100 lb). It is found in all warm and temperate oceans. The longest bony fish is the king of herrings. Its total length can reach 11 metres (36 ft), and it can weigh up to 272 kilograms (600 lb). It is a rarely seen oarfish found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



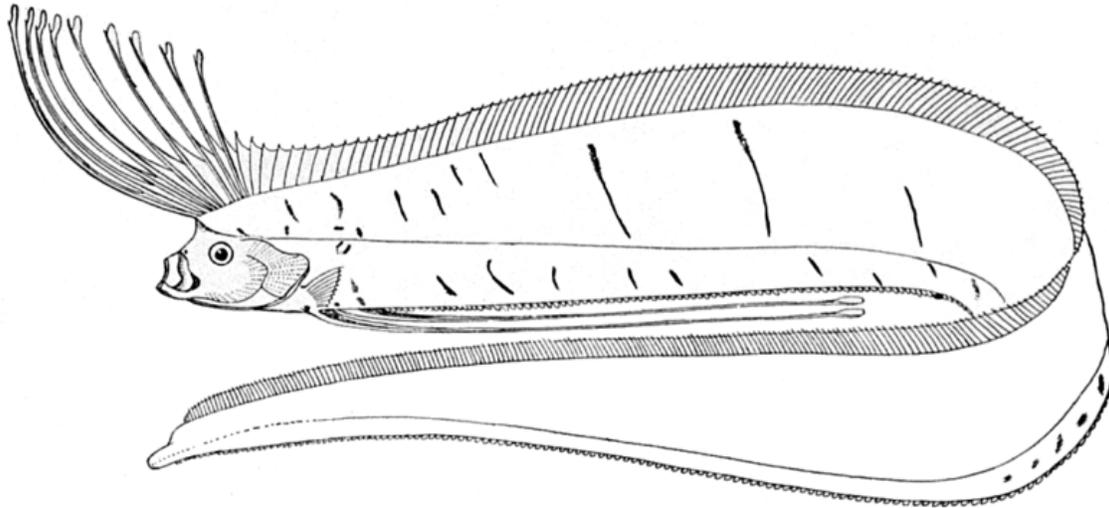
Some of the smallest fishes are minnow-type fishes, including the smallest of all, *Paedocypris progenetica*.



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 roughey 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

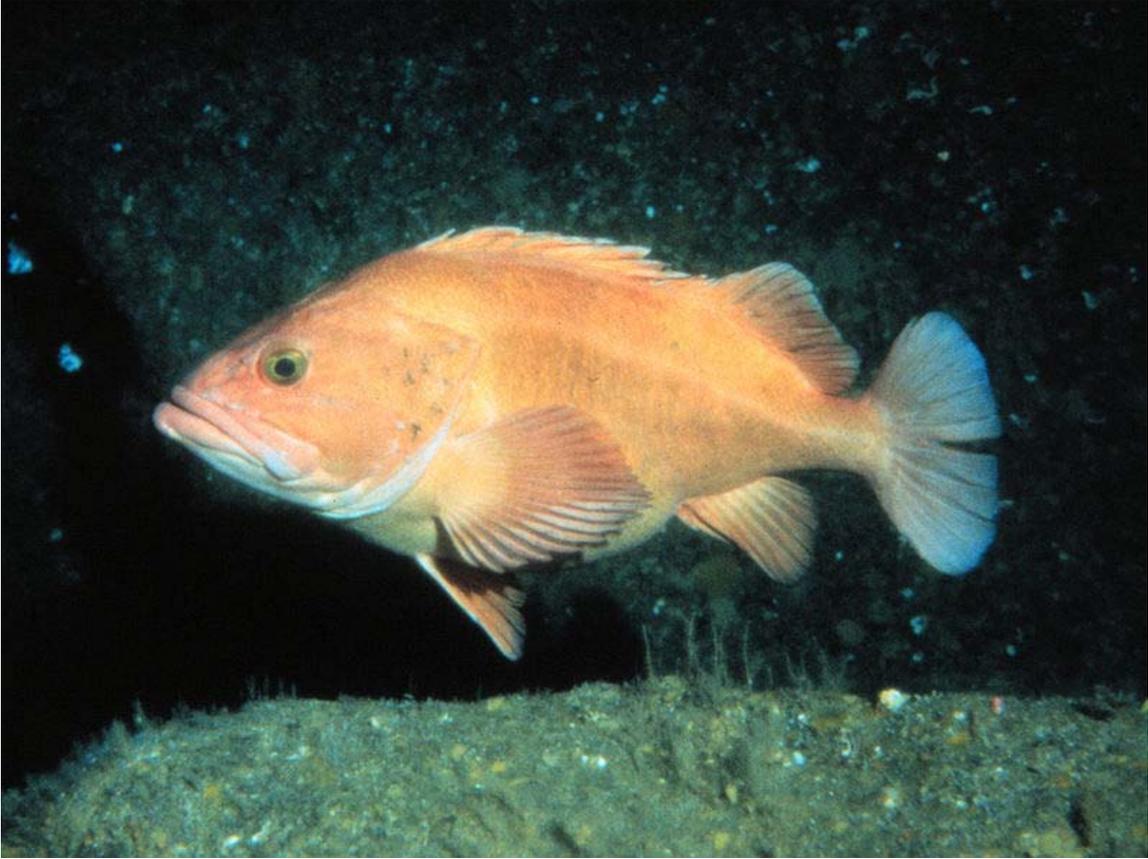
The longest living commercial fish may be the orange roughy, with a maximum reported age of 149 years. One of the longest living sport fish is the Atlantic tarpon, with a maximum reported age of 55 years."

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

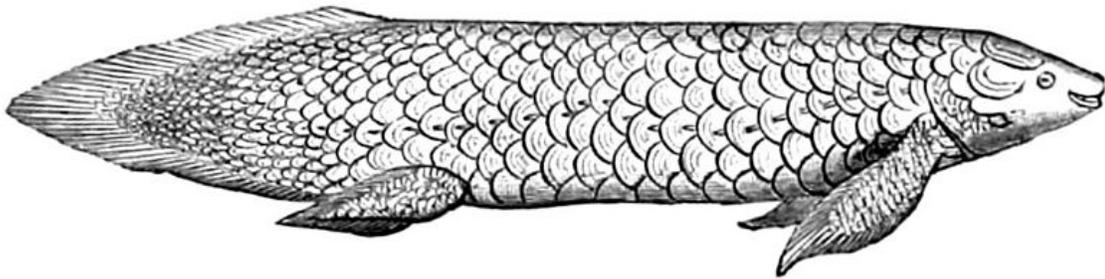
aquarium for 75 years, and is the oldest fish in captivity. According to fossil records, the Australian lungfish has hardly changed for 380 million years.



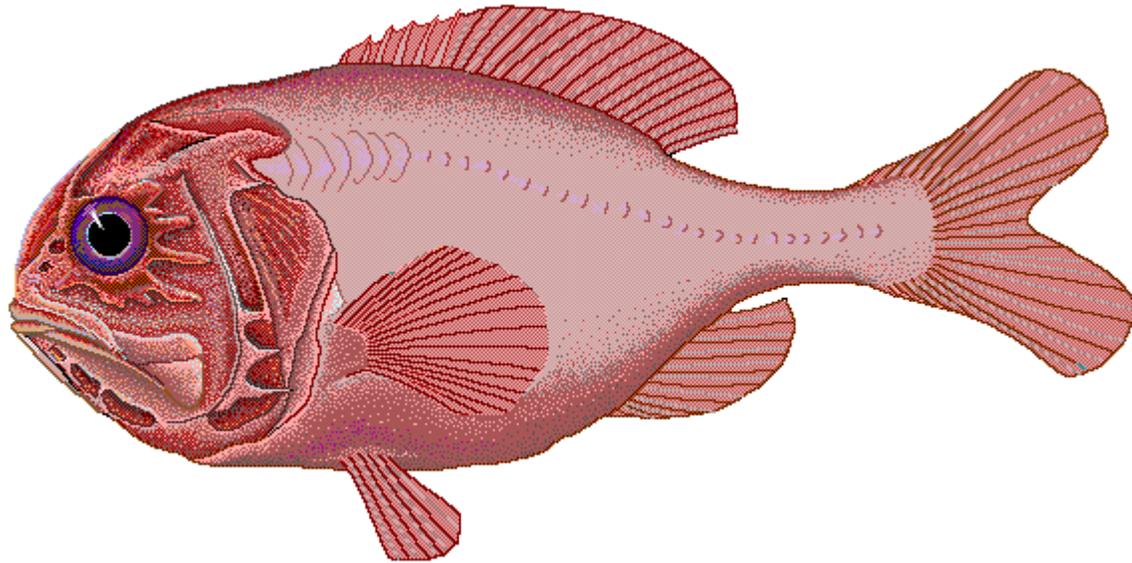
Among gobies, small coral reef-dwelling fish, are some of the shortest lived fishes with the seven-figure pygmy goby living at most for 59 days.



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 million km²	Volume million cu km	Depth (mean)	Species count	Species percent	Fish biomass 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 galathea*, a species of cusk eel, lives in the Puerto Rico Trench at a depth of 8,372 meters (27,467 ft). At the other extreme, the Tibetan stone loach lives at altitudes over 5,200 meters (17,060 ft) in the Himalayas.

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



The blue shark ranges across all oceans



The blind cave fish live in caves

By breeding behavior

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

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

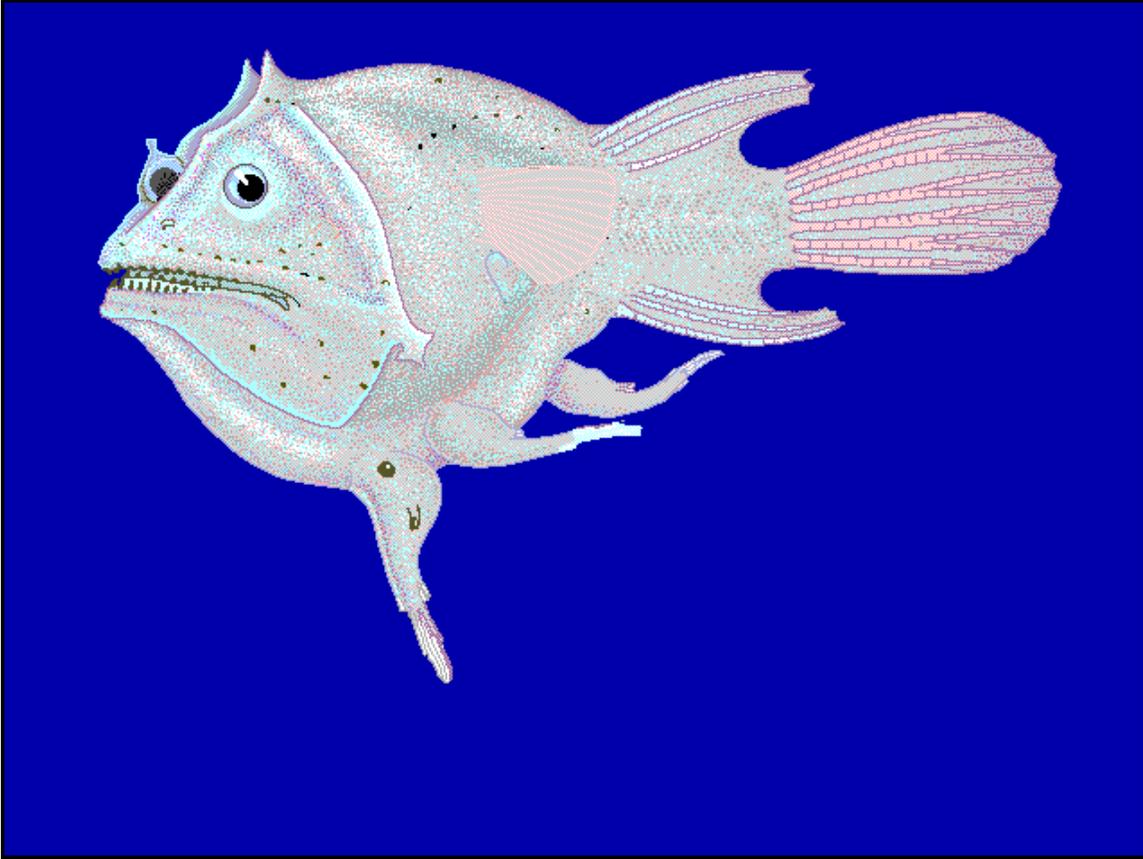
Some sharks, such as hammerheads are able to breed parthogenetically.



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



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



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

By brooding behavior

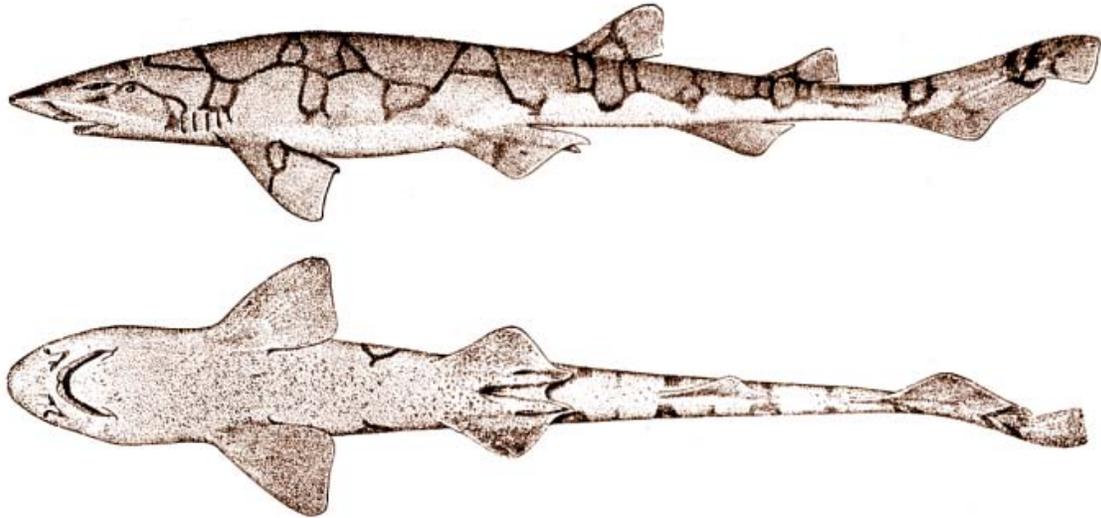
Fish adopt a variety of strategies for nurturing their brood. Sharks, for example, variously follow three protocols with their brood. Most sharks, including lamniformes are ovoviviparous, bearing their young after they nourish themselves after hatching and before birth, by consuming the remnants of the yolk and other available nutrients. Some such as hammerheads are viviparous, bearing their young after nourishing hatchlings internally, analogously 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 teleosts 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.

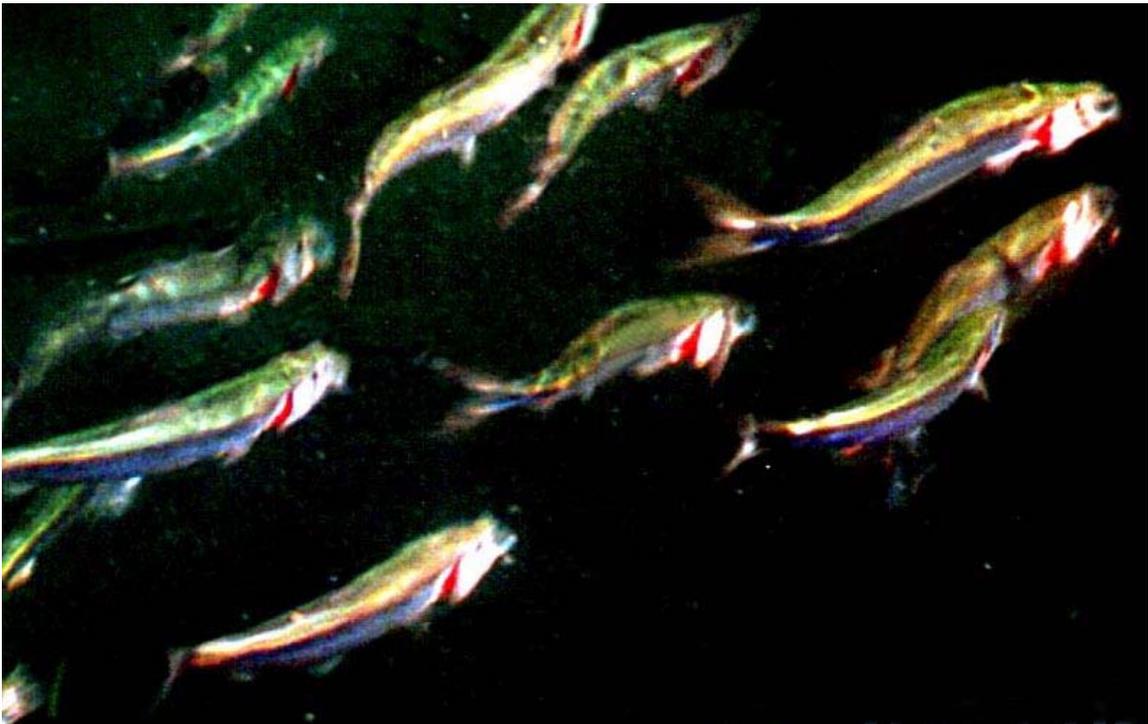


The Emperor angelfish feeds on coral sponges

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.



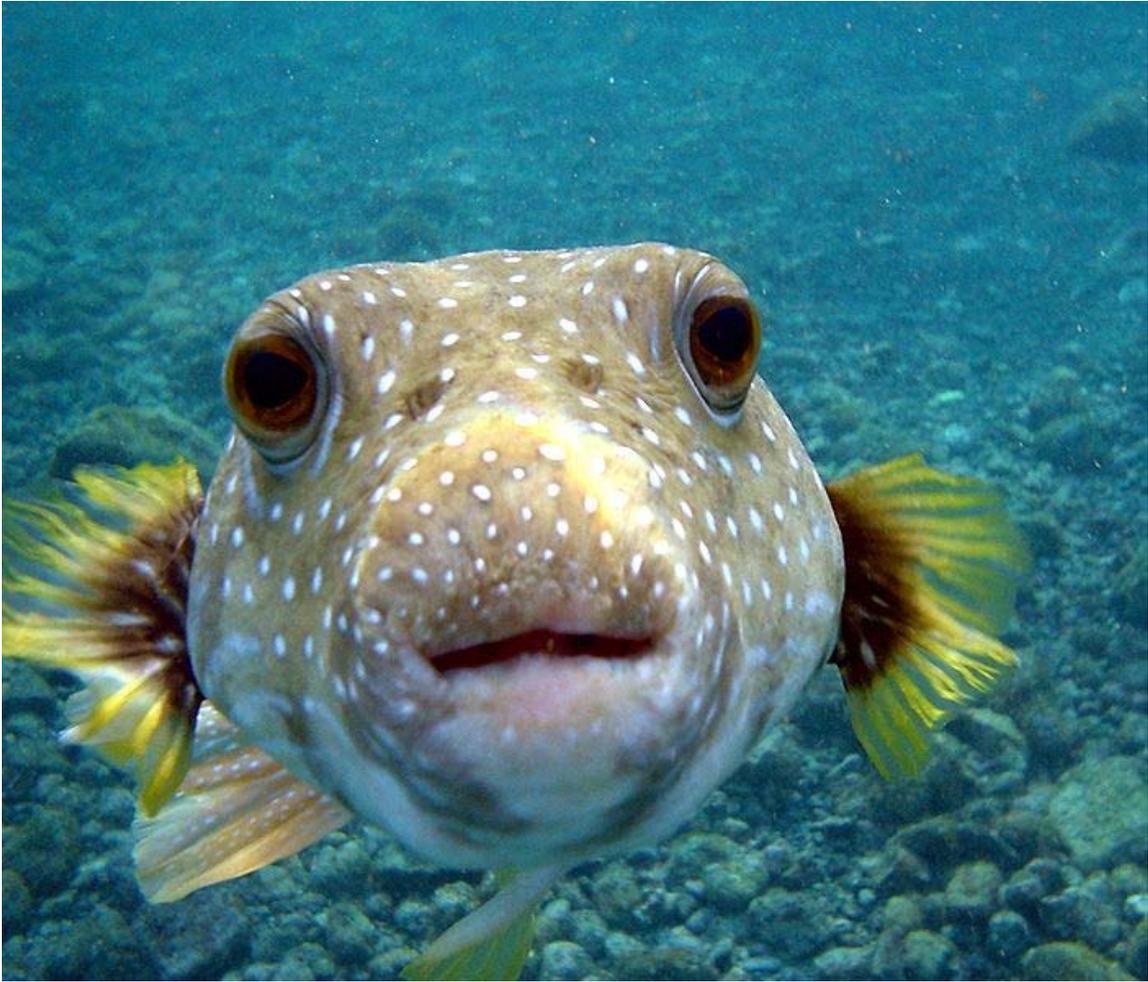
Silver arowana leap two metres out of the water to capture prey.



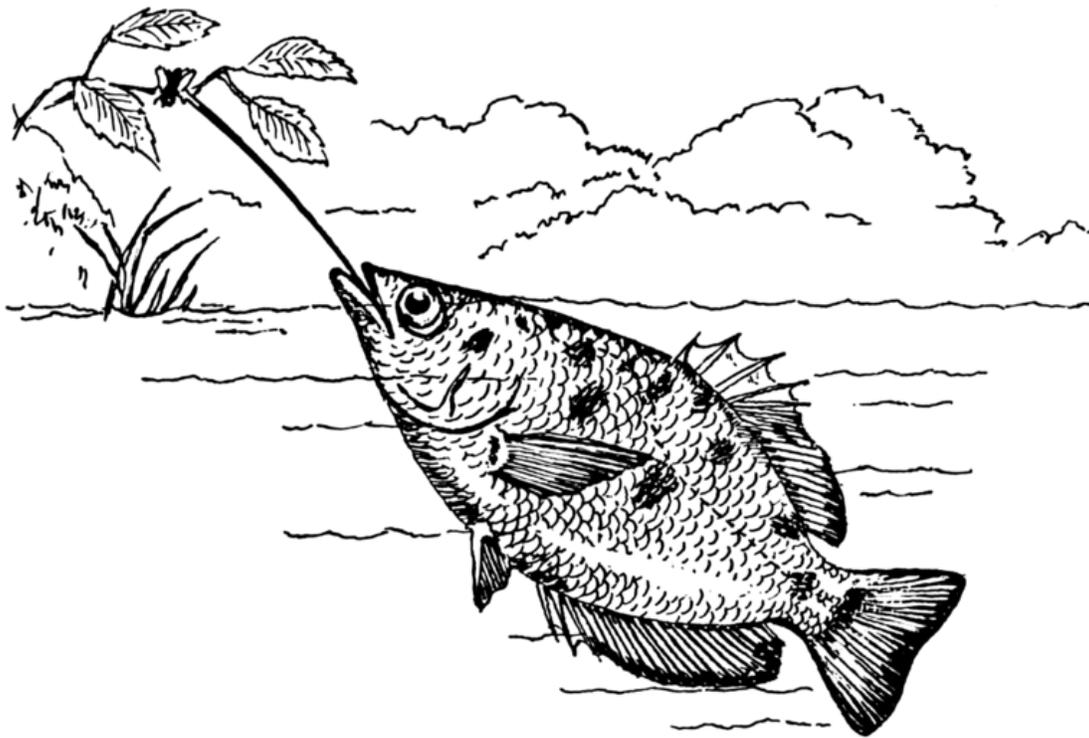
Schooling herrings ram feed on copepods



The mangrove jack eats crustaceans



Many puffer fish species crush the shells of molluscs



Archerfish shooting down an insect using a jet of water

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

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



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



The bucktoothed tetra eats scales off other fishes (lepidophagy)



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



Doctor fish nibbling on the diseased skin of patients

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

By locomotion

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

Among the fastest 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.

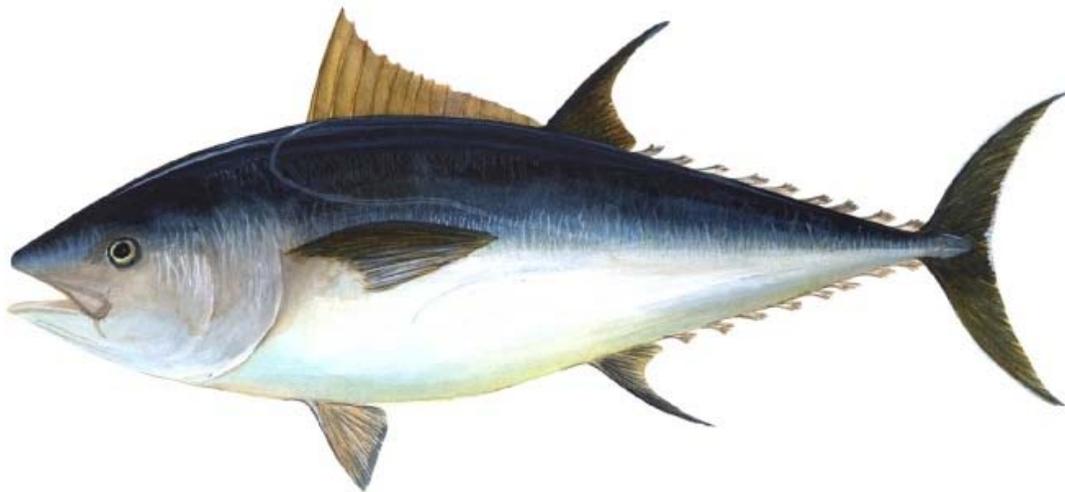
The northern bluefin tuna is capable of sustained high speed cruising, and maintains high muscle temperatures so it can cruise in arctic waters.



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



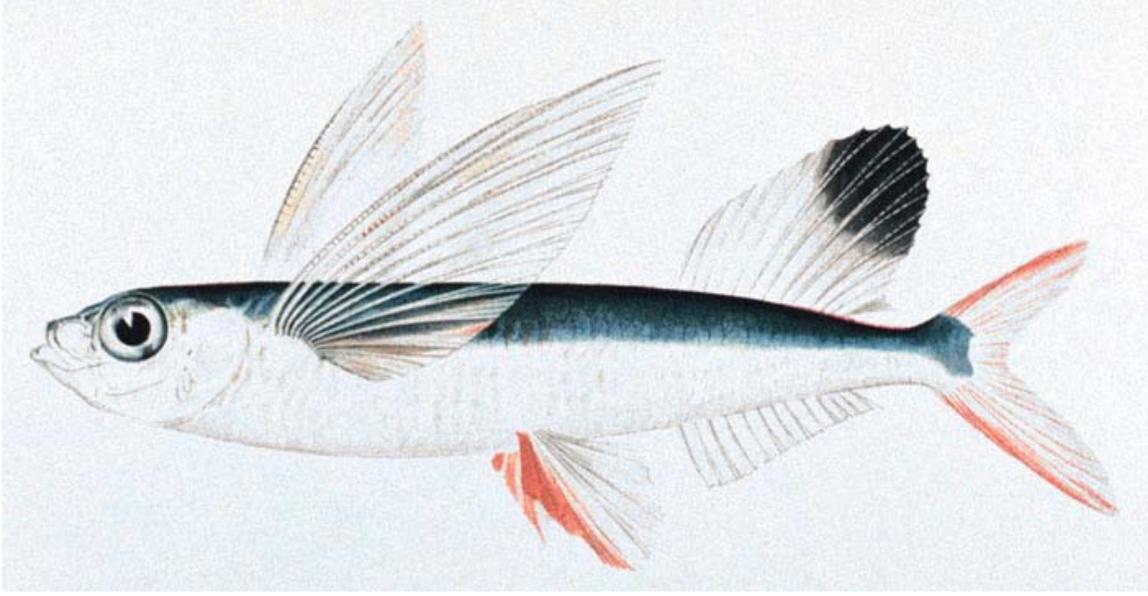
One of the fastest sprinters is the Indo-Pacific sailfish



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".

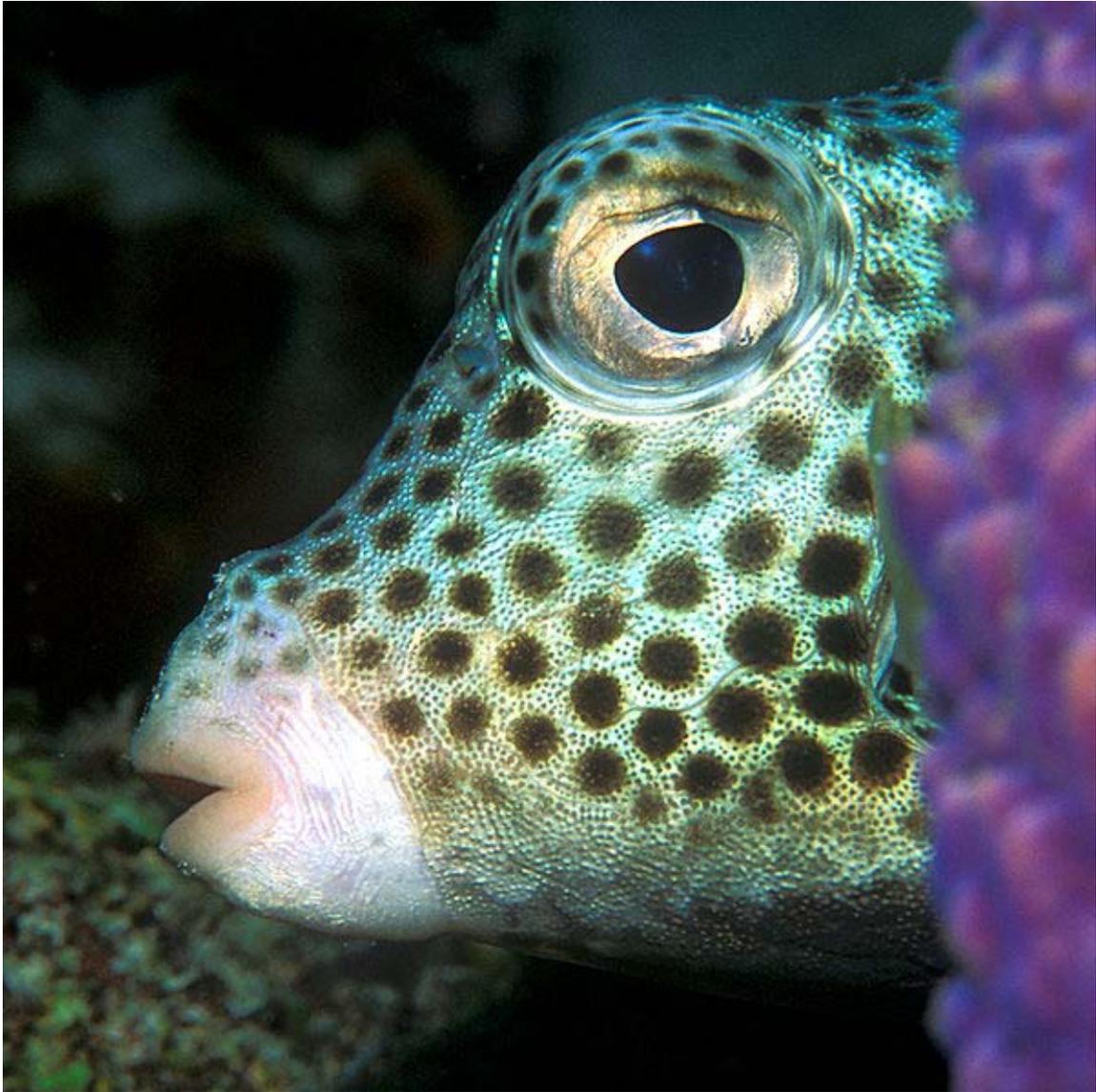
The spotted trunkfish is a reef fish which secretes a colourless ciguatera toxin from glands on its skin when touched. The toxin is only dangerous when ingested, so there's no immediate harm to divers. However, predators as large as nurse sharks can die as a result of eating a trunkfish.

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



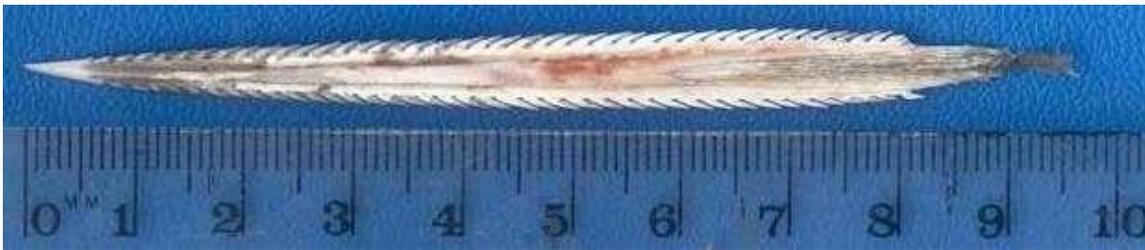
The stargazer *Uranoscopus sulphureus*.

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.

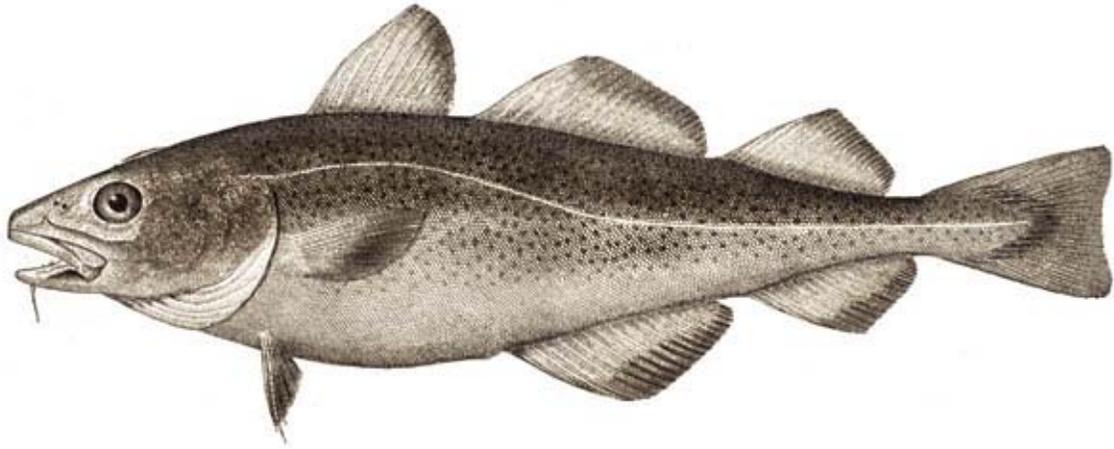
Higher in the food chain, Gadidae (cod, pollock, haddock, saithe, hake and whiting also support important fisheries. Concentrated initially in the North Sea, Atlantic cod was one of Europe's oldest fisheries, later extending to the Grand Banks, Declining numbers led to international "cod wars" and eventually 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.

Other types



Four-eyed fish

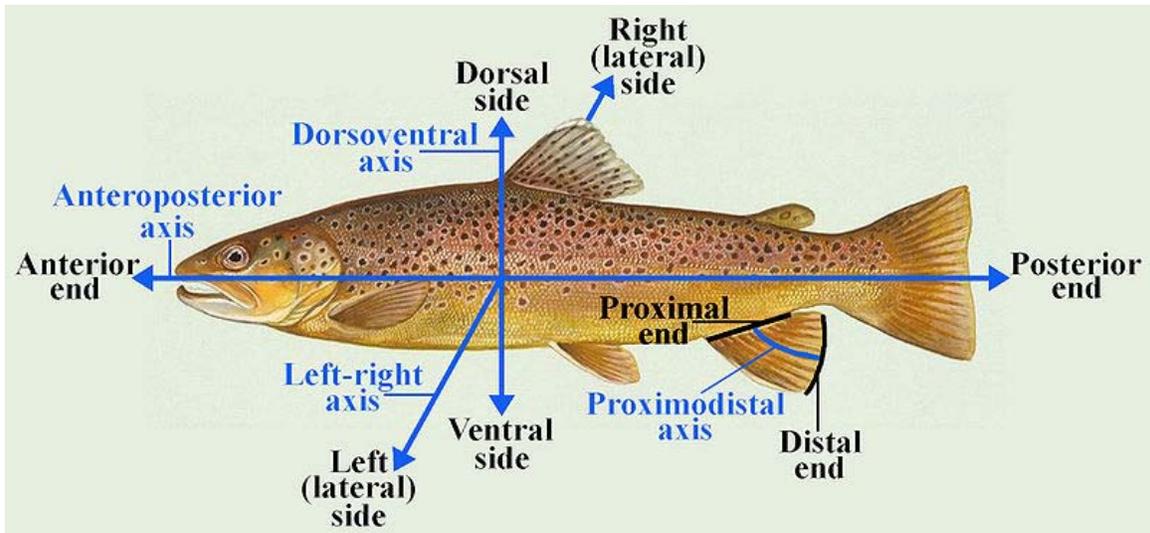
Four-eyed fish have eyes raised above the top of the head and divided in two different parts, so that they can see below and above the water surface at the same time. Four-eyed fish actually have only two eyes, but their eyes are specially adapted for their surface-dwelling lifestyle. The eyes are positioned 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 bathypelagic 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- 4

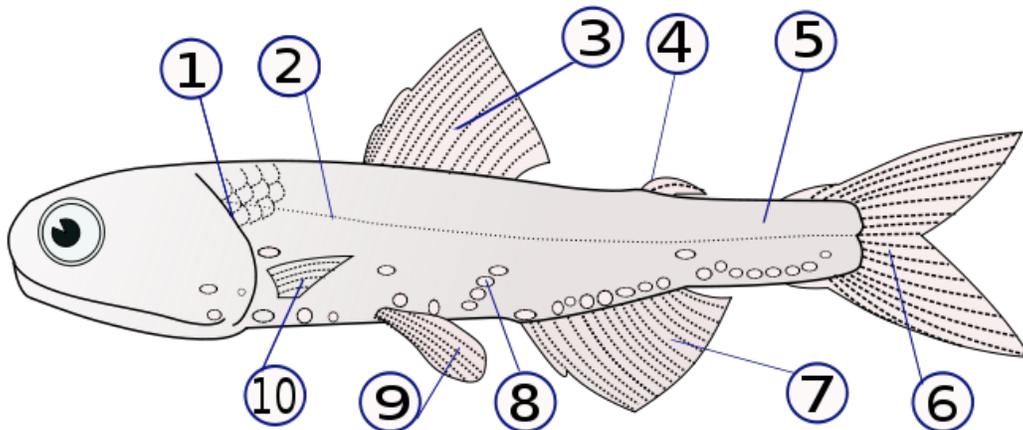
Anatomy of Fish



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.

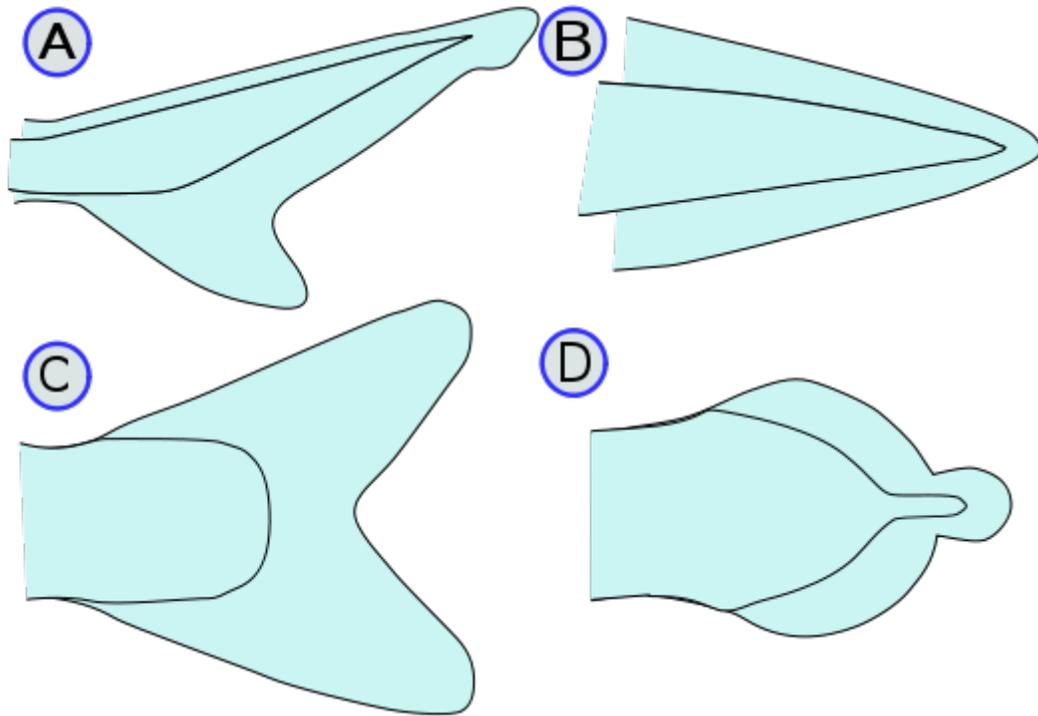
Spines and rays

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.



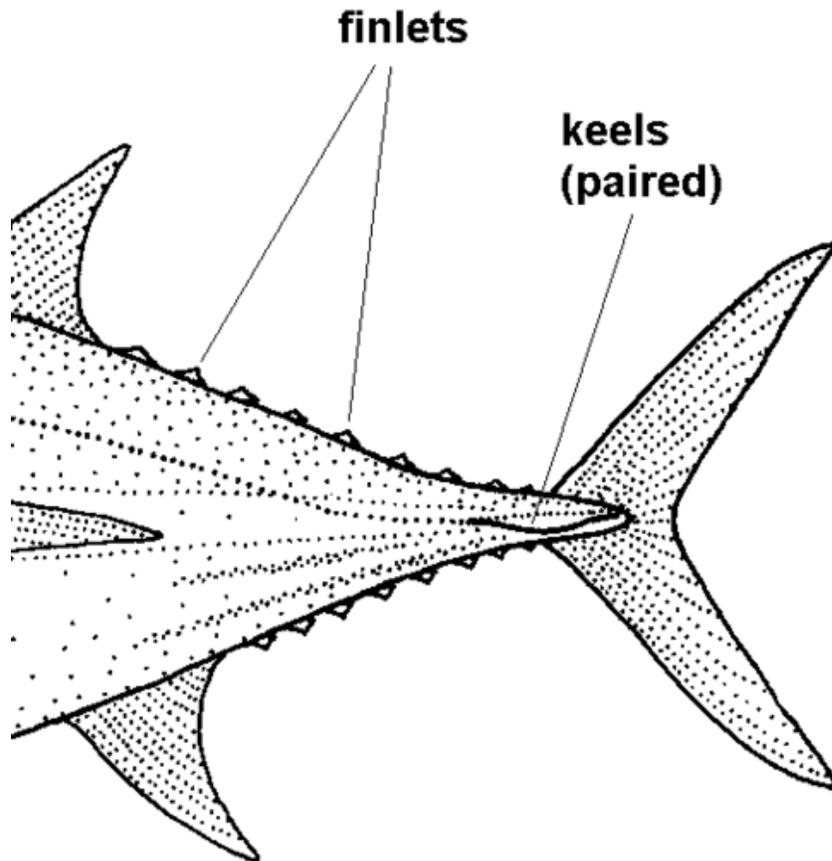
types of caudal fin :

(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** 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.
- 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, 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 cartilaginous fish, such as sharks, the vertebrae consist of two cartilaginous tubes. The upper tube is formed from the vertebral arches, but also includes additional cartilaginous 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.

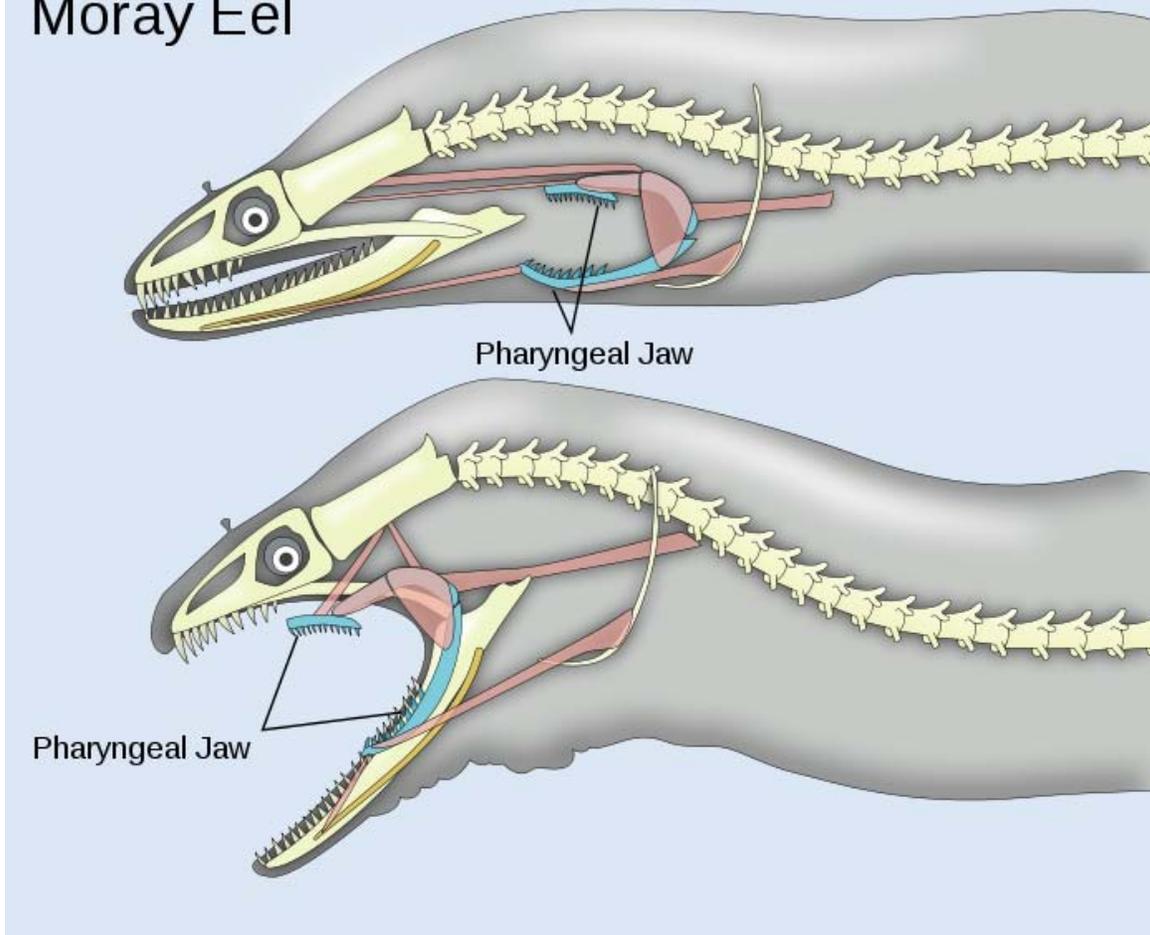
Lampreys have vertebral arches, but nothing resembling the vertebral bodies found in all higher vertebrates. Even the arches are discontinuous, consisting of separate pieces of arch-shaped cartilage around the spinal cord in most parts of the body, changing to long strips of cartilage above and below 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 Eel



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.

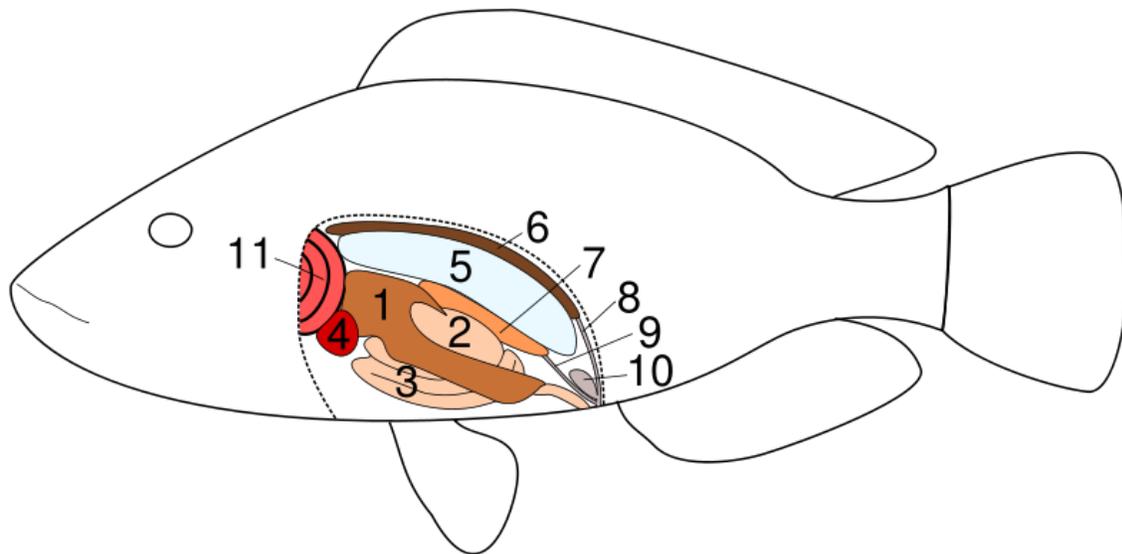
Linkage mechanisms are especially frequent and manifold in the head of bony fishes, such as wrasses, which have evolved many specialized feeding mechanisms. Especially advanced are the linkage mechanisms of jaw protrusion. For suction feeding a system of linked four-bar linkages is responsible for the 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- 5

Fish Importance to Humans

Fish (food)



Fish served with vegetables and herbs.

Fish is a food consumed by many species, including humans. The word "fish" refers to both the animal and to the food prepared from it. Fish has been an important source of protein for humans throughout recorded history.

The term "fish"

Some languages distinguish between fish as an animal and the food prepared from it. However other languages, such as English or French, do not make this distinction, and the same word used to refer to a live fish in the ocean is also used to refer to food prepared from it. In English this applies also to chicken but not to pork and beef.

The modern English word for fish comes from the Old English word 'fisc' (plural: fiscas), which was pronounced as it is today.

Nutrition



Fried fish and chips in San Diego.

Fish, especially saltwater fish, is high in omega 3 fatty acids, which are heart-friendly, and a regular diet of fish is highly recommended by nutritionists. This is conjectured to be one of the major causes of reduced risk for cardiovascular diseases in the Inuit. It has been suggested that the longer lifespan of Japanese and Nordic populations may be

partially due to their higher consumption of fish and seafood. The Mediterranean diet is likewise based on a rich intake of fish. Nutritionists recommend that fish be eaten at least 2-3 times a week.

Health hazards

Fish is the most common food to obstruct the airway and cause choking. Fish was responsible for about 4,500 accidents in the UK in 1998. In addition, fish can also cause poisoning, especially when the fish is caught in polluted areas. To avoid fish poisoning it is thus advised to consume fish that is caught in unpolluted water. In addition, it is also helpful to consume fish species that do not accumulate much toxins/metals. Some organisations such as SeafoodWatch, RIKILT, Environmental Defense Fund, IMARES provide information on species that do not accumulate much toxins/metals.

Heavy metals

Heavy metals are mostly accumulated in "greasy" fish species such as salmon and herring, as well as in "soil fishes" such as eel, carp and bream.

Mercury

Fish products have been shown to contain varying amounts of heavy metals, particularly mercury and fat-soluble pollutants from water pollution. According to the US Food and Drug Administration (FDA), the risk from mercury by eating fish and shellfish is not a health concern for most people. However, certain seafood contains sufficient mercury to harm an unborn baby or young child's developing nervous system. The FDA makes three recommendations for child-bearing women and young children:

1. Do not eat shark, swordfish, king mackerel, or tilefish because they contain high levels of mercury.
2. Eat up to 12 ounces (2 average meals) a week of a variety of fish and shellfish that are lower in mercury. Four of the most commonly eaten fish that are low in mercury are canned light tuna, salmon, pollock, and catfish. Another commonly eaten fish, albacore ("white tuna") has more mercury than canned light tuna. So, when choosing your two meals of fish and shellfish, you may eat up to 6 ounces (one average meal) of albacore tuna per week.
3. Check local advisories about the safety of fish caught by family and friends in your local lakes, rivers, and coastal areas. If no advice is available, eat up to 6 ounces (one average meal) per week of fish you catch from local waters, but don't consume any other fish during that week.

These recommendations are also advised when feeding fish and shellfish to young children, but in smaller portions.

Lead

Besides mercury, lead is also frequently found in fish.

Chlorine

Besides mercury, chlorine is also frequently found in fish.

Bromine

Besides mercury, bromine is also frequently found in fish.

PCB's and dioxins

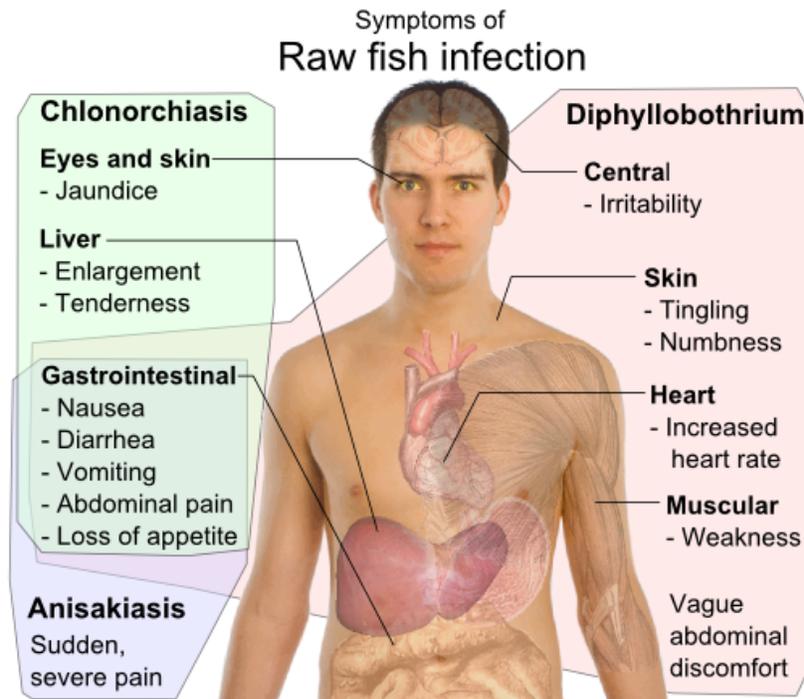
There are also issues with PCBs and dioxins.

Biotoxins

A lot of fish eat algae and other organisms that contain biotoxins (defensive substances against predators). Biotoxins accumulated in fish/shellfish include (but are not limited to): brevetoxins, okada acid, saxitoxins, ciguatoxine and domoic acid. Except for ciguatoxine, high levels of these toxins are only found in shellfish. Both domoic acid and ciguatoxine can be deadly to humans; the others will only cause diarrhea, dizziness and a (temporary) feeling of claustrophobia.

Some species of fish, notably the puffer fugu used for sushi, and some kinds of shellfish, can cause severe biopoisoning if not prepared properly. These fish always contain these poisons as a defense against predators; it is not present due to environmental circumstances. Particularly, fugu has a lethal dose of tetrodotoxin in its internal organs and must be prepared by a licensed fugu chef who has passed the national examination in Japan.

Parasites



Differential symptoms of parasite infections by raw fish. All have gastrointestinal, but otherwise distinct, symptoms.

Parasites in fish are a natural occurrence and common. Though not a health concern in thoroughly cooked fish, parasites are a concern when 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 (*sake*) in Salmonidae or 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.

Fish and meat

Meat is animal flesh that is used as food. Most often, this means the skeletal muscle and associated fat, but it may also describe other edible organs and tissues. The term "meat" is used by the meat packing industry in a more restrictive sense—the flesh of mammalian species (pigs, cattle, etc.) raised and prepared for human consumption, to the exclusion of fish and poultry.

Typical Meat Nutritional Content from 110 grams (4 oz or .25 lb)				
Source	calories	protein	carbs	fat
fish	110–140	20–25 g	0 g	1–5 g
chicken breast	160	28 g	0 g	7 g
lamb	250	30 g	0 g	14 g
steak (beef top round)	210	36 g	0 g	7 g
steak (beef T-bone)	450	25 g	0 g	35 g

Vegetarians don't eat fish, and consider that fish is meat, since it is the flesh of an animal.

However, pescetarians eat fish and other seafood, but not mammals and birds. The Merriam-Webster dictionary dates the origin of the term "pescetarian" to 1993 and defines it to mean: "one whose diet includes fish but no meat." Pescetarians may consume fish based solely upon the fact that the fish are not factory farmed as land animals are (i.e., their problem is with the capitalist-industrial production of meat, not with the consumption of animal foods themselves). Some eat fish with the justification that fish have less sophisticated nervous systems than land-dwelling animals. Others may choose to consume only wild fish based upon the lack of confinement, while choosing to not consume fish that have been farmed.

In religion

Religious rites and rituals regarding food also tend to classify the birds of the air and the fish of the sea separately from land-bound mammals. Sea-bound mammals are often treated as fish under religious laws - as in Jewish dietary law, which forbids the eating of whale, dolphin, porpoise, and orca because they are not "fish with fins and scales"; nor, as mammals, do they chew their cud and have cloven hooves, as required by Leviticus 11:9-12. Jewish (kosher) practice treat fish differently from other animal foods. The distinction between fish and "meat" is codified by the Jewish dietary law of *kashrut*, regarding the mixing of milk and meat, which does not forbid the mixing of milk and fish. Modern Jewish legal practice (*halakha*) on *kashrut* classifies the flesh of both

mammals and birds as "meat"; fish are considered to be *parve*, neither meat nor a dairy food.

Seasonal religious prohibitions against eating meat do not usually include fish. For example, non-fish meat was forbidden during Lent and on all Fridays of the year in pre-Vatican II Roman Catholicism, but fish was permitted (as were eggs). In Eastern Orthodoxy, fish is permitted on some fast days when other meat is forbidden, but stricter fast days also prohibit fish with spines, while permitting invertebrate seafood such as shrimp and oysters, considering them "fish without blood."

Some Buddhists and Hindus (Brahmins of West Bengal, Orissa and Saraswat Brahmins of the Konkan) abjure meat that is not fish. For hundreds of years before the opening of Japan, most Japanese did not eat meat. Muslim (halaal) practice also treats fish differently from other animal foods.

Preparation

Seafoods can be prepared in a variety of ways. It can be uncooked (raw) (*cf.* sashimi). It can be cured by marinating (*cf.* escabeche), pickling (*cf.* pickled herring), or smoking (*cf.* smoked salmon). Or it can be cooked by baking, frying (*cf.* fish and chips), grilling, poaching (*cf.* court-bouillon), or steaming. Many of the preservation techniques used in different cultures have since become unnecessary but are still performed for their resulting taste and texture when consumed.

Fishing industry



Modern Spanish tuna purse seiner in the Seychelles Islands

The **fishing industry** includes any industry or activity concerned with taking, culturing, processing, preserving, storing, transporting, marketing or selling fish or fish products.

It is defined by the FAO as including recreational, subsistence and commercial fishing, and the harvesting, processing, and marketing sectors. The commercial activity is aimed at the delivery of fish and other seafood products for human consumption or as input factors in other industrial processes. Directly or indirectly, the livelihood of over 500 million people in developing countries depends on fisheries and aquaculture.

Sectors

There are three principal industry sectors:

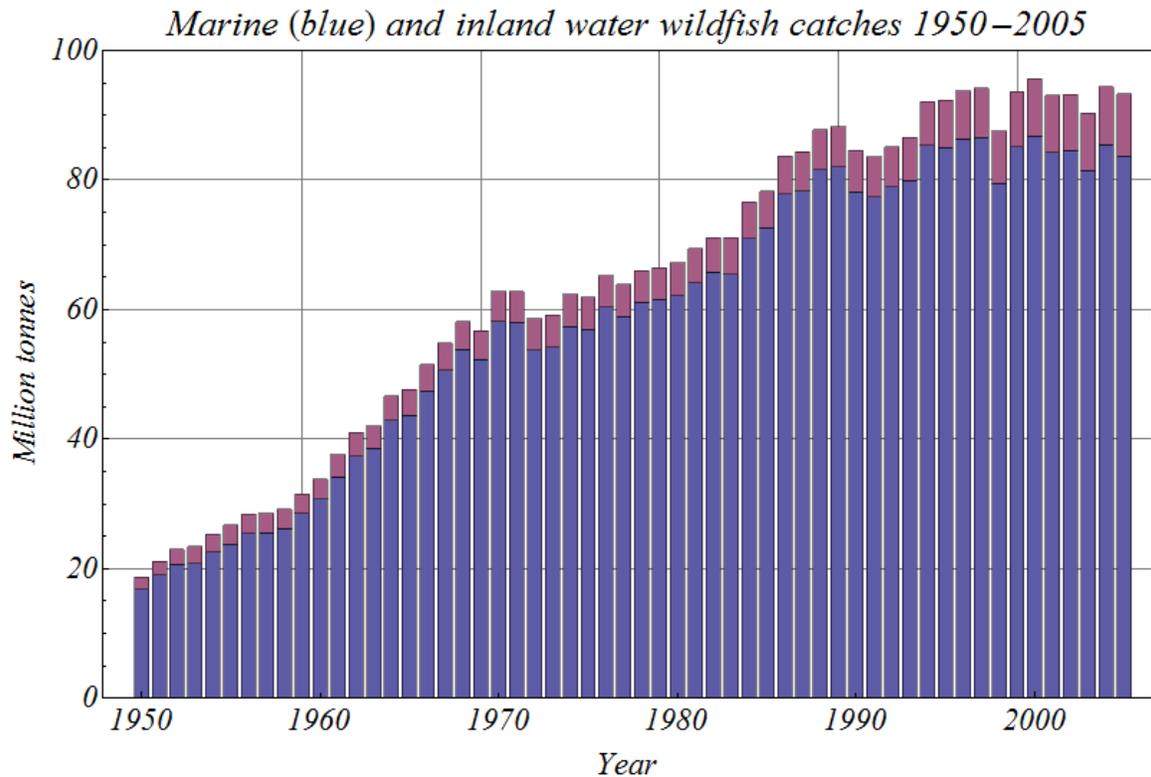
- **The commercial sector:** comprises enterprises and individuals associated with wild-catch or aquaculture resources and the various transformations of those resources into products for sale. It is also referred to as the "seafood industry", although non-food items such as pearls are included among its products.
- **The traditional sector:** comprises enterprises and individuals associated with fisheries resources from which aboriginal people derive products in accordance with their traditions.
- **The recreational sector:** comprises enterprises and individuals associated for the purpose of recreation, sport or sustenance with fisheries resources from which products are derived that are not for sale.

Commercial sector

The commercial sector of the fishing industry comprises the following chain:

1. Commercial fishing and fish farming which produce the fish
2. Fish processing which produce the fish products
3. Marketing of the fish products

World production



FAO catch statistics, world catches 1950-2005 in million tonnes.

Fish are harvested by commercial fishing and aquaculture.

According to the Food and Agriculture Organization (FAO), the world harvest in 2005 consisted of 93.3 million tonnes captured by commercial fishing in wild fisheries, plus 48.1 million tonnes produced by fish farms. In addition, 1.3 million tons of aquatic plants (seaweed etc) were captured in wild fisheries and 14.8 million tons were produced by aquaculture.

Following is a table of the 2005 world fishing industry harvest in tonnes by capture and by aquaculture.

	Capture	Aquaculture	Total
Fish, crustaceans, molluscs, etc	93,253,346	48,149,792	141,403,138
Aquatic plants	1,305,803	14,789,972	16,095,775
Total	94,559,149	62,939,764	157,498,913

This equates to about 24.4 kilograms a year for the average person on Earth.

Commercial fishing



Double-rigged shrimp trawler hauling in the nets

The top producing countries were, in order, the People's Republic of China (excluding Hong Kong and Taiwan), Peru, Japan, the United States, Chile, Indonesia, Russia, India, Thailand, Norway and Iceland. Those countries accounted for more than half of the world's production; China alone accounted for a third of the world's production.

Fish farming



Intensive koi aquaculture facility in Israel

Aquaculture is the cultivation of aquatic organisms. Unlike fishing, aquaculture, also known as aquafarming, is the cultivation of aquatic populations under controlled conditions. Mariculture refers to aquaculture practiced in marine environments. Particular kinds of aquaculture include algaculture (the production of kelp/seaweed and other algae); fish farming; shrimp farming, shellfish farming, and the growing of cultured pearls.

Fish farming involves raising fish commercially in tanks or enclosed pools, usually for food. Fish species raised by fish farms include carp, salmon, tilapia, catfish and cod. Increasing demands on wild fisheries by commercial fishing operations have caused widespread overfishing. Fish farming offers an alternative solution to the increasing market demand for fish and fish protein.

Fish processing



Tuna under the knife

Fish processing is the processing of fish delivered by commercial fisheries and fish farms. The larger fish processing companies have their own fishing fleets and independent fisheries. The products of the industry are usually sold wholesale to grocery chains or to intermediaries.

Fish processing can be subdivided into two categories: fish handling (the initial processing of raw fish) and fish products manufacturing. Aspects of fish processing occur on fishing vessels, fish processing vessels, and at fish processing plants.

Another natural subdivision is into primary processing involved in the filleting and freezing of fresh fish for onward distribution to fresh fish retail and catering outlets, and the secondary processing that produces chilled, frozen and canned products for the retail and catering trades.

Fish products



Sea urchin roe.

Fisheries are estimated to currently provide 16% of the world population's protein. The flesh of many fish are primarily valued as a source of food; there are many edible species of fish. Other marine life taken as food includes shellfish, crustaceans, sea cucumber, jellyfish and roe.

Fish and other marine life are also be used for many other uses: pearls and mother-of-pearl, sharkskin and rayskin. Sea horses, star fish, sea urchins and sea cucumber are used in traditional Chinese medicine. Tyrian purple is a pigment made from marine snails, sepia is a pigment made from the inky secretions of cuttlefish. Fish glue has long been valued for its use in all manner of products. Isinglass is used for the clarification of wine and beer. Fish emulsion is a fertilizer emulsion that is produced from the fluid remains of fish processed for fish oil and fish meal.

In the industry the term *seafood products* is often used instead of *fish products*.

Fish marketing



Fresh seafood laid out on one of several floating barge vendors.

Fish markets are marketplace used for the trade in and sale of fish and other seafood. They can be dedicated to wholesale trade between fishermen and fish merchants, or to the sale of seafood to individual consumers, or to both. Retail fish markets, a type of wet market, often sell street food as well.

Most shrimps are sold frozen and are marketed in different categories. The live food fish trade is a global system that links fishing communities with markets.

Traditional sector



Fishing in Cà Mau, Vietnam.

The traditional fishing industry, or artisan fishing, are terms used to describe small scale commercial or subsistence fishing practises, particularly using traditional techniques such as rod and tackle, arrows and harpoons, throw nets and drag nets, etc. It does not usually cover the concept of fishing for sport, and might be used when talking about the pressures between large scale modern commercial fishing practises and traditional methods, or when aid programs are targeted specifically at fishing at or near subsistence levels.

Recreational sector



Fly fishing in a river

The recreational fishing industry consists of enterprises such as the manufacture and retailing of fishing tackle and apparel, the payment of license fees to regulatory authorities, fishing books and magazines, the design and building of recreational fishing boats, and the provision of accommodation, fishing boats for charter, and guided fishing adventures.

Fish farming



Intensive koi aquaculture facility in Israel

Fish farming is the principal form of aquaculture, while other methods may fall under mariculture. Fish farming involves raising fish commercially in tanks or enclosures, usually for food. A facility that releases young (juvenile) fish into the wild for recreational fishing or to supplement a species' natural numbers is generally referred to as a fish hatchery. The most common fish species raised by fish farms are salmon, carp, tilapia, European seabass, catfish and cod.

Increasing demands on wild fisheries by commercial fishing has caused widespread overfishing. Fish farming offers an alternative solution to the increasing market demand for fish and fish protein.

Major categories of fish farms

There are two kinds of aquaculture: extensive aquaculture based on local photosynthetic production and intensive aquaculture, in which the fish are fed with external food supply. The management of these two kinds of aquaculture systems are completely different.

Extensive aquaculture



Aqua-Boy, a Norwegian live fish carrier used to service the Marine Harvest fish farms on the West coast of Scotland

Limiting for growth here is the available food supply by natural sources, commonly zooplankton feeding on pelagic algae or benthic animals, such as crustaceans and mollusks. Tilapia species filter feed directly on phytoplankton, which makes higher production possible. The photosynthetic production can be increased by fertilizing the pond water with artificial fertilizer mixtures, such as potash, phosphorus, nitrogen and micro-elements. Because most fish are carnivorous, they occupy a higher place in the trophic chain and therefore only a tiny fraction of primary photosynthetic production (typically 1%) will be converted into harvest-able fish. As a result, without additional feeding the fish harvest will not exceed 200 kilograms of fish per hectare per year, equivalent to 1% of the gross photosynthetic production.

A second point of concern is the risk of algal blooms. When temperatures, nutrient supply and available sunlight are optimal for algal growth, algae multiply their biomass at an exponential rate, eventually leading to an exhaustion of available nutrients and a subsequent die-off. The decaying algal biomass will deplete the oxygen in the pond water because it blocks out the sun and pollutes it with organic and inorganic solutes (such as ammonium ions), which can (and frequently do) lead to massive loss of fish.

Another option is to use a wetland system such as that of Veta La Palma.

In order to tap all available food sources in the pond, the aquaculturist will choose fish species which occupy different places in the pond ecosystem, e.g., a filter algae feeder such as tilapia, a benthic feeder such as carp or catfish and a zooplankton feeder (various carps) or submerged weeds feeder such as grass carp.

Despite these limitations significant fish farming industries use these methods. In the Czech Republic thousands of natural and semi-natural ponds are harvested each year for

trout and carp. The large ponds around Trebon were built from around 1650 and are still in use.

Sources

- Introduction to Aquaculture, college notes, Department of Aquaculture, Wageningen University
- Aquaculture: training manual, second edition, Donald R. Swift, ISBN 0-85238-194-8

Intensive aquaculture

In these kinds of systems fish production per unit of surface can be increased at will, as long as sufficient oxygen, fresh water and food are provided. Because of the requirement of sufficient fresh water, a massive water purification system must be integrated in the fish farm. A clever way to achieve this is the combination of hydroponic horticulture and water treatment. The exception to this rule are cages which are placed in a river or sea, which supplements the fish crop with sufficient oxygenated water. Some environmentalists object to this practice.



Expressing eggs from a female rainbow trout

The cost of inputs per unit of fish weight is higher than in extensive farming, especially because of the high cost of fish feed, which must contain a much higher level of protein

(up to 60%) than cattle food and a balanced amino acid composition as well. However, these higher protein level requirements are a consequence of the higher food conversion efficiency (FCR—kg of feed per kg of animal produced) of aquatic animals. Fish like salmon have FCR's in the range of 1.1 kg of feed per kg of salmon whereas chickens are in the 2.5 kg of feed per kg of chicken range. Fish don't have to stand up or keep warm and this eliminates a lot of carbohydrates and fats in the diet, required to provide this energy. This frequently is offset by the lower land costs and the higher productions which can be obtained due to the high level of input control.

Essential here is aeration of the water, as fish need a sufficient oxygen level for growth. This is achieved by bubbling, cascade flow or aqueous oxygen. Catfish, *Clarias* ssp. can breathe atmospheric air and can tolerate much higher levels of pollutants than trout or salmon, which makes aeration and water purification less necessary and makes *Clarias* species especially suited for intensive fish production. In some *Clarias* farms about 10% of the water volume can consist of fish biomass.

The risk of infections by parasites like fish lice, fungi (*Saprolegnia* ssp.), intestinal worms (such as nematodes or trematodes), bacteria (e.g., *Yersinia* ssp, *Pseudomonas* ssp.), and protozoa (such as Dinoflagellates) is similar to animal husbandry, especially at high population densities. However, animal husbandry is a larger and more technologically mature area of human agriculture and better solutions to pathogen problem exist. Intensive aquaculture does have to provide adequate water quality (oxygen, ammonia, nitrite, etc.) levels to minimize stress, which makes the pathogen problem more difficult. This means, intensive aquaculture requires tight monitoring and a high level of expertise of the fish farmer.



Controlling roes manually

Very high intensity recycle aquaculture systems (RAS), where there is control over all the production parameters, are being used for high value species. By recycling the water, very little water is used per unit of production. However, the process does have high capital and operating costs. The higher cost structures mean that RAS is only economical for high value products like broodstock for egg production, fingerlings for net pen aquaculture operations, sturgeon production, research animals and some special niche markets like live fish.

Raising ornamental cold water fish (goldfish or koi), although theoretically much more profitable due to the higher income per weight of fish produced, has never been successfully carried out until very recently. The increased incidences of dangerous viral diseases of koi Carp, together with the high value of the fish has led to initiatives in closed system koi breeding and growing in a number of countries. Today there are a few commercially successful intensive koi growing facilities in the UK, Germany and Israel.

Some producers have adapted their intensive systems in an effort to provide consumers with fish that do not carry dormant forms of viruses and diseases.

Specific types of fish farms

Within intensive and extensive aquaculture methods there are numerous specific types of fish farms, each has benefits and applications unique to its design.

Integrated recycling systems

One of the largest problems with freshwater aquaculture is that it can use a million gallons of water per acre (about 1 m³ of water per m²) each year. Extended water purification systems allow for the reuse (recycling) of local water.

The largest-scale pure fish farms use a system derived (admittedly much refined) from the New Alchemy Institute in the 1970s. Basically, large plastic fish tanks are placed in a greenhouse. A hydroponic bed is placed near, above or between them. When tilapia are raised in the tanks, they are able to eat algae, which naturally grows in the tanks when the tanks are properly fertilized.

The tank water is slowly circulated to the hydroponic beds where the tilapia waste feeds commercial plant crops. Carefully cultured microorganisms in the hydroponic bed convert ammonia to nitrates, and the plants are fertilized by the nitrates and phosphates. Other wastes are strained out by the hydroponic media, which doubles as an aerated pebble-bed filter.

This system, properly tuned, produces more edible protein per unit area than any other. A wide variety of plants can grow well in the hydroponic beds. Most growers concentrate on herbs (e.g. parsley and basil), which command premium prices in small quantities all year long. The most common customers are restaurant wholesalers.

Since the system lives in a greenhouse, it adapts to almost all temperate climates, and may also adapt to tropical climates. The main environmental impact is discharge of water that must be salted to maintain the fishes' electrolyte balance. Current growers use a variety of proprietary tricks to keep fish healthy, reducing their expenses for salt and waste water discharge permits. Some veterinary authorities speculate that ultraviolet ozone disinfectant systems (widely used for ornamental fish) may play a prominent part in keeping the Tilapia healthy with recirculated water.

A number of large, well-capitalized ventures in this area have failed. Managing both the biology and markets is complicated.

Reference: *Freshwater Aquaculture: A Handbook for Small Scale Fish Culture in North America*, by William McLarney

Irrigation ditch or pond systems

These use irrigation ditches or farm ponds to raise fish. The basic requirement is to have a ditch or pond that retains water, possibly with an above-ground irrigation system (many irrigation systems use buried pipes with headers.) Using this method, one can store one's water allotment in ponds or ditches, usually lined with bentonite clay. In small systems the fish are often fed commercial fish food, and their waste products can help fertilize the fields. In larger ponds, the pond grows water plants and algae as fish food. Some of the

most successful ponds grow introduced strains of plants, as well as introduced strains of fish.

Control of water quality is crucial. Fertilizing, clarifying and pH control of the water can increase yields substantially, as long as eutrophication is prevented and oxygen levels stay high. Yields can be low if the fish grow ill from electrolyte stress.

Composite fish culture

The Composite fish culture system is a technology developed in India by the Indian Council of Agricultural Research in the 1970s. In this system both local and imported fish species, a combination of five or six fish species is used in a single fish pond. These species are selected so that they do not compete for food among them having different types of food habitats. As a result the food available in all the parts of the pond is used. Fish used in this system include catla and silver carp which are surface feeders, rohu a column feeder and mrigal and common carp which are bottom feeders. Other fish will also feed on the excreta of the common carp and this helps contribute to the efficiency of the system which in optimal conditions will produce 3000–6000 kg of fish per hectare per year.

Cage system



Giant gourami is often raised in cages in central Thailand

Fish cages are placed in lakes, bayous, ponds, rivers or oceans to contain and protect fish until they can be harvested. They can be constructed of a wide variety of components. Fish are stocked in cages, artificially fed, and harvested when they reach market size. A few advantages of fish farming with cages are that many types of waters can be used (rivers, lakes, filled quarries, etc.), many types of fish can be raised, and fish farming can co-exist with sport fishing and other water uses. Cage farming of fishes in open seas is also gaining popularity. Concerns of disease, poaching, poor water quality, etc., lead some to believe that in general, pond systems are easier to manage and simpler to start. Also, past occurrences of cage-failures leading to escapes, have raised concern regarding the culture of non-native fish species in open-water cages. Even though the cage-industry has made numerous technological advances in cage construction in recent years, the concern for escapes remains valid.

Classic fry farming

Trout and other sport fish are often raised from eggs to fry or fingerlings and then trucked to streams and released. Normally, the fry are raised in long, shallow concrete tanks, fed with fresh stream water. The fry receive commercial fish food in pellets. While not as efficient as the New Alchemists' method, it is also far simpler, and has been used for many years to stock streams with sport fish. European eel (*Anguilla anguilla*) aquaculturalists procure a limited supply of glass eels, juvenile stages of the European eel which swim north from the Sargasso Sea breeding grounds, for their farms. The European eel is threatened with extinction because of the excessive catch of glass eels by Spanish fishermen and overfishing of adult eels in, e.g., the Dutch IJsselmeer, Netherlands. As per 2005, no one has managed to breed the European eel in captivity.

Issues

The issue of feeds in fish farming has been a controversial one. Many cultured fishes (tilapia, carp, catfish, many others) require no meat or fish products in their diets. Top-level carnivores (most salmon species) depend on fish feed of which a portion is usually derived from wild caught fish (anchovies, menhaden, etc.). Vegetable-derived proteins have successfully replaced fish meal in feeds for carnivorous fishes, but vegetable-derived oils have not successfully been incorporated into the diets of carnivores.

Secondly, farmed fish are kept in concentrations never seen in the wild (e.g. 50,000 fish in a 2-acre (8,100 m²) area.) with each fish occupying less room than the average bathtub. This can cause several forms of pollution. Packed tightly, fish rub against each other and the sides of their cages, damaging their fins and tails and becoming sickened with various diseases and infections. This also causes stress.

However, fish tend also to be animals that aggregate into large schools at high density. Most successful aquaculture species are schooling species, which do not have social problems at high density. Aquaculturists tend to feel that operating a rearing system above its design capacity or above the social density limit of the fish will result in decreased growth rate and increased FCR (food conversion ratio - kg dry feed/kg of fish

produced), which will result in increased cost and risk of health problems along with a decrease in profits. Stressing the animals is not desirable, but the concept of and measurement of stress must be viewed from the perspective of the animal using the scientific method.

Sea lice, particularly *Lepeophtheirus salmonis* and various *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 *nauplii* 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%.

A 2008 meta-analysis of available data shows that salmon farming reduces the survival of associated wild salmon populations. This relationship has been shown to hold for Atlantic, steelhead, pink, chum, and coho salmon. The decrease in survival or abundance often exceeds 50 percent.

Some species of sea lice have been noted to target farmed coho and Atlantic salmon. Such parasites have been shown to have an effect on nearby wild fish. One place that has garnered international media attention is British Columbia's Broughton Archipelago. There, juvenile wild salmon must "run a gauntlet" of large fish farms located off-shore near river outlets before making their way to sea. It is alleged that the farms cause such severe sea lice infestations that one study predicted a 99% collapse in the wild salmon population in another four years. This claim, however, has been criticized by numerous scientists who question the correlation between increased fish farming and increases in sea lice infestation among wild salmon.

Because of parasite problems, some aquaculture operators frequently use strong antibiotic drugs to keep the fish alive (but many fish still die prematurely at rates of up to 30 percent). In some cases, these drugs have entered the environment. Additionally, the residual presence of these drugs in human food products has become controversial. Use of antibiotics in food production is thought to increase the prevalence of antibiotic resistance in human diseases. At some facilities, the use of antibiotic drugs in aquaculture has decreased considerably due to vaccinations and other techniques. However, most fish farming operations still use antibiotics, many of which escape into the surrounding environment.

The lice and pathogen problems of the 1990s facilitated the development of current treatment methods for sea lice and pathogens. These developments reduced the stress from parasite/pathogen problems. However, being in an ocean environment, the transfer of disease organisms from the wild fish to the aquaculture fish is an ever-present risk.

The very large number of fish kept long-term in a single location contributes to habitat destruction of the nearby areas. The high concentrations of fish produce a significant amount of condensed faeces, often contaminated with drugs, which again affect local waterways. However, these effects are very local to the actual fish farm site and are minimal to non-measurable in high current sites.

Concern remains that resultant bacterial and algae growth strips the water of oxygen, reducing or killing off the local marine life. Once an area has been so contaminated, the fish farms are moved to new, uncontaminated areas. This practice has angered nearby fishermen.

Other potential problems faced by aquaculturists are the obtaining of various permits and water-use rights, profitability, concerns about invasive species and genetic engineering depending on what species are involved, and interaction with the United Nations Convention on the Law of the Sea.

In regards to genetically modified farmed salmon, concern has been raised over their proven reproductive advantage and how it could potentially decimate local fish populations, if released into the wild. Biologist Rick Howard did a controlled laboratory study where wild fish and GMO fish were allowed to breed. The GMO fish crowded out the wild fish in spawning beds, but the offspring were less likely to survive. The Center for Food Safety criticized the FDA's analysis as misguided and dangerous. Federal tests were "insufficient in determining the long-term, unforeseen consequences" of genetic engineering, said Wenonah Hauter, director of Food & Water Watch. The FDA's tests (historically used to determine if a non-GM food was safe) were created before GM products became a reality and are insufficient in determining the long-term, unforeseen consequences of the GM salmon in question. These dated tests cannot determine the salmon's full allergenicity and toxicity. The FDA is reviewing data submitted by AquaBounty, the company that spliced a growth hormone gene into Atlantic salmon, forcing it to grow up to five times faster, and reach market size in about 18 months instead of 3 years. According to the evidence, their salmon might have higher levels of a cancer promoting hormone IGF-1, more antibiotics, and more of a potentially life-threatening allergen(s).

The colorant used to make pen-raised salmon appear rosy like their wild cousins has been linked with retinal problems in humans.

Labeling

In 2005, Alaska passed legislation requiring that any genetically altered fish sold in the state be labeled. In 2006, a Consumer Reports investigation revealed that farm-raised salmon is frequently sold as wild.

In 2008, the US National Organic Standards Board allowed farmed fish to be labeled as organic provided less than 25% of their feed came from wild fish. This decision was

criticized by the advocacy group Food & Water Watch as "bending the rules" about organic labeling. In the European Union, fish labeling as to species, method of production and origin, has been required since 2002.

Concerns continue over the labeling of salmon as farmed or wild caught, as well as about the humane treatment of farmed fish. The Marine Stewardship Council has established an Eco label to distinguish between farmed and wild caught salmon, while the RSPCA has established the Freedom Food label to indicate humane treatment of farmed salmon as well as other food products.

Indoor fish farming

An alternative to outdoor open ocean cage aquaculture, one in which the risk of environmental damage is high, is through the use of a recirculation aquaculture system (RAS). A RAS is a series of culture tanks and filters where water is continuously recycled and monitored to keep optimal conditions year round. To prevent the deterioration of water quality, the water is treated mechanically through the removal of particulate matter and biologically through the conversion of harmful accumulated chemicals into nontoxic ones.

Other treatments such as UV sterilization, ozonation, and oxygen injection are also used to maintain optimal water quality. Through this system, many of the environmental drawbacks of aquaculture are minimized including escaped fish, water usage, and the introduction of pollutants. The practices also increased feed-use efficiency growth by providing optimum water quality (Timmons et al., 2002; Piedrahita, 2003).

One of the drawbacks to recirculation aquaculture systems is water exchange. However, the rate of water exchange can be reduced through aquaponics, such as the incorporation of hydroponically grown plants (Corpron and Armstrong, 1983) and denitrification (Klas et al., 2006). Both methods reduce the amount of nitrate in the water, and can potentially eliminate the need for water exchanges, closing the aquaculture system from the environment. The amount of interaction between the aquaculture system and the environment can be measured through the cumulative feed burden (CFB kg/M³), which measures the amount of feed that goes into the RAS relative to the amount of water and waste discharged.

Because of its high capital and operating costs, RAS has generally been restricted to practices such as broodstock maturation, larval rearing, fingerling production, research animal production, SPF (specific pathogen free) animal production, and caviar and ornamental fish production. Although the use of RAS for other species is considered by many aquaculturalists to be impractical, there has been some limited successful implementation of this with high value product such as barramundi, sturgeon and live tilapia in the US.

Slaughter methods

Tanks saturated with carbon dioxide have been used to make fish unconscious. Then their gills are cut with a knife so that the fish bleed out before they are further processed. This is no longer considered a humane method of slaughter. Methods that induce much less physiological stress are electrical or percussive stunning and this has led to the phasing out of the carbon dioxide slaughter method in Europe.

Fishkeeping



An aquascaped freshwater aquarium

Fishkeeping is a popular hobby concerned with keeping fish in a home aquarium or garden pond. There is also a fishkeeping industry, as a branch of agriculture.

Types of fishkeeping systems

Fishkeepers are often known as "aquarists", since many of them are not solely interested in keeping fish. The hobby can be broadly divided into three specific disciplines according to the type of water the fish tolerate: freshwater, brackish, and marine (also called saltwater) fishkeeping.

Freshwater

Freshwater fishkeeping is by far the most popular branch of the hobby, with even small pet stores often selling a variety of freshwater fish, such as goldfish, guppies, and angelfish. While most freshwater aquaria are community tanks containing a variety of compatible species, single-species breeding aquaria are also popular. Livebearing fish such as mollies and guppies are among those most easily raised in captivity, but aquarists also regularly breed many types of cichlid, catfish, characin, and killifish.

Many fishkeepers create freshwater aquascapes where the focus is on aquatic plants as well as fish. These aquaria include "Dutch Aquaria", named for European aquarists who designed them. In recent years, one of the most active advocates of the heavily planted aquarium is the Japanese aquarist Takashi Amano.

Garden ponds are in some ways similar to freshwater aquaria, but are usually much larger and exposed to ambient weather. In the tropics, tropical fish can be kept in garden ponds, but in the temperate zone species such as goldfish, koi, and orfe work better.

Saltwater

Marine aquaria are generally more difficult to maintain and the livestock is significantly more expensive. As a result this branch tends to attract more experienced fishkeepers. Marine aquaria can be exceedingly beautiful, due to the attractive colors and shapes of the corals and the coral reef fish they host. Temperate zone marine fish are not as commonly kept in home aquaria, primarily because they do not thrive at room temperature. Coldwater aquaria must provide cooler temperature via a cool room (such as an unheated basement) or a refrigeration device known as a 'chiller'.

Marine aquarists often attempt to recreate a coral reef in their aquaria using large quantities of living rock, porous calcareous rocks encrusted with coralline algae, sponges, worms, and other small marine organisms. Larger corals as well as shrimps, crabs, echinoderms, and mollusks are added later on, once the aquarium has matured, as well as a variety of small fish. Such aquaria are sometimes called reef tanks.

Brackish water

Brackish water aquaria combine elements of the other types, with salinity that must stay between that of freshwater and seawater. Brackish water fish come from habitats with varying salinity, such as mangroves and estuaries, and do not thrive if kept permanently in freshwater. Although brackish water aquaria are not necessarily familiar to inexperienced aquarists, many species prefer brackish water, including some mollies, many gobies, some pufferfish, monos, scats, and virtually all the freshwater soles.

The origins of fishkeeping



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

Fish have been raised as food in pools and ponds for thousands of years. Brightly colored or tame specimens of fish in these pools have sometimes been valued as pets rather than food. Many other cultures kept fish for both functional and decorative purposes.

Ancient Sumerians kept wild-caught fish in ponds, before preparing them for meals. Depictions of the sacred fish of *Oxyrhynchus* kept in captivity in rectangular temple pools have been found in ancient Egyptian art.

Similarly, Asia has experienced a long history of stocking rice paddies with freshwater fish suitable for eating, including various types of catfish and cyprinid. Selective breeding of carp into today's popular and completely domesticated koi and goldfish began over 2,000 years ago in Japan and China, respectively. The Chinese brought goldfish indoors during the Song Dynasty to enjoy them in large ceramic vessels.

In Medieval Europe, carp pools were a standard feature of estates and monasteries, providing an alternative to meat on feast days when meat could not be eaten for religious reasons.

Marine fish have been similarly valued for centuries. Wealthy Romans kept lampreys and other fish in salt water pools. Tertullian reports that Asinius Celer paid 8000 sesterces for a particularly fine mullet. Cicero reports that the advocate Quintus Hortensius wept when a favored specimen died. Rather cynically, he referred to these ancient fishkeepers as the Piscinarii, the "fish-pond owners" or "fish breeders", for example when saying that *...the rich (I mean your friends the fish-breeders) did not disguise their jealousy of me.*

Aquarium maintenance



A 335,000 U.S. gallon (1.3 million litre) aquarium at the Monterey Bay Aquarium in California displaying a simulated kelp forest ecosystem

Ideal aquarium ecology reproduces the balance found in nature in the closed system of an aquarium. In practice it is virtually impossible to maintain a perfect balance. As an example, a balanced predator-prey relationship is nearly impossible to maintain in even the largest aquaria. Typically, an aquarium keeper must actively maintain balance in the small ecosystems that aquaria provide.

Balance is facilitated by larger volumes of water which dilute the effects of a systemic shock. For example, the death of the only fish in a 10 litres (2.2 imp gal; 2.6 US gal) tank causes dramatic changes in the system, while the death of that same fish in a 400 litres (88 imp gal; 110 US gal) tank that holds many fish creates only a minor imbalance. For

this reason, hobbyists often favor larger tanks when possible, as they require less intensive attention.

A variety of nutrient cycles are important in the aquarium. Dissolved oxygen enters at the surface water-air interface or through the actions of an air pump. Carbon dioxide escapes into the air. The phosphate cycle is an important, although often overlooked, nutrient cycle. Sulfur, iron, and micronutrients enter the system as food and exit as waste. Appropriate handling of the nitrogen cycle, along with a balanced food supply and consideration of biological loading, is usually enough to keep these nutrient cycles in adequate equilibrium.

Water conditions

The solute content of water is perhaps the most important aspect of water conditions, as total dissolved solids and other constituents can dramatically impact basic water chemistry, and therefore how organisms interact with their environment. Salt content, or salinity, is the most basic classification of water conditions. An aquarium may have freshwater (salinity below 0.5 PPT), simulating a lake or river environment; brackish water (a salt level of 0.5 to 30 PPT), simulating environments lying between fresh and salt, such as estuaries; and salt water or seawater (a salt level of 30 to 40 PPT), simulating an ocean or sea environment. Even higher salt concentrations are maintained in specialized tanks for raising brine organisms.

Several other water characteristics result from dissolved materials in the water, and are important to the proper simulation of natural environments. Saltwater is typically alkaline, while the pH of fresh water varies. "Hardness" measures overall dissolved mineral content; hard or soft water may be preferred. Hard water is usually alkaline, while soft water is usually neutral to acidic. Dissolved organic content and dissolved gases content are also important factors.

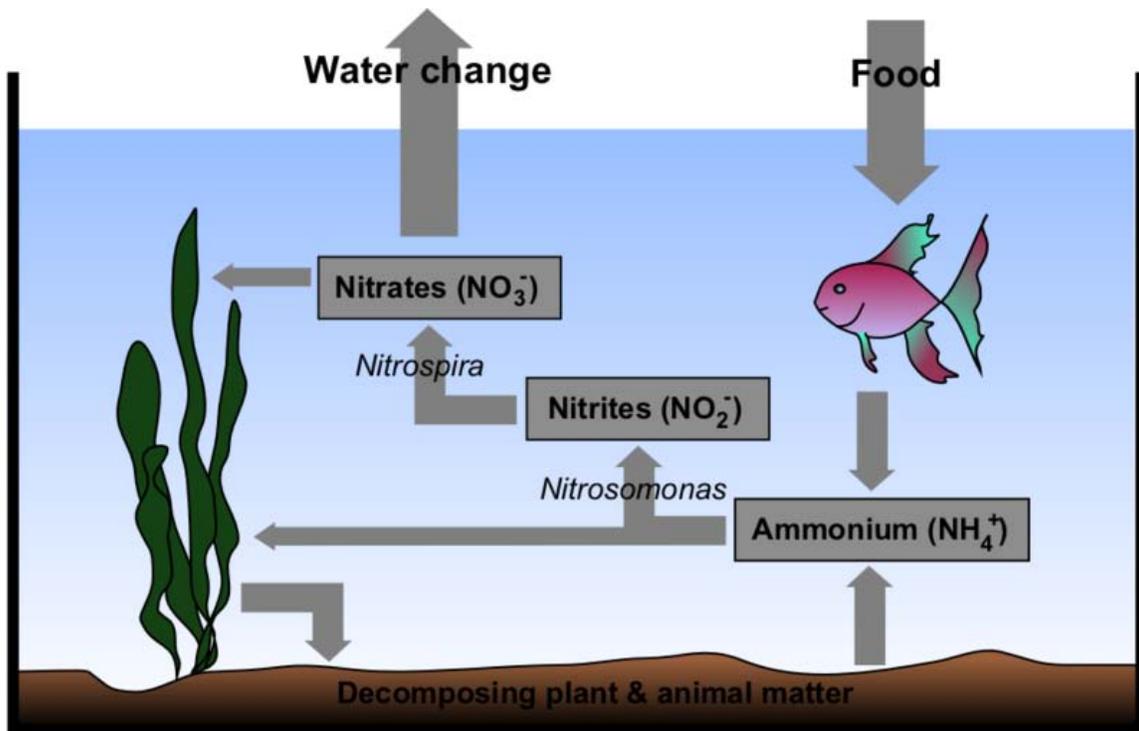
Home aquarists typically use modified tap water supplied through their local water supply network. Because of the chlorine used to disinfect drinking water supplies for human consumption, tap water cannot be immediately used. In the past, it was possible to "condition" the water by simply letting the water stand for a day or two, which allows the chlorine to dissipate. However, chloramine became popular in water treatment because it stays longer in the water. Additives are available to remove chlorine or chloramine and suffice to make the water ready. Brackish or saltwater aquaria require the addition of a mixture of salts and other minerals.

More sophisticated aquarists may modify the water's alkalinity, hardness, or dissolved content of organics and gases. This can be accomplished by additives such as sodium bicarbonate to raise pH. Some aquarists filter or purify their water using one of two processes: deionization or reverse osmosis. In contrast, public aquaria with large water needs often locate themselves near a natural water source (such as a river, lake, or ocean) in order to have easy access to water that requires only minimal treatment.

Water temperature forms the basis of one of the two most basic aquarium classifications: tropical vs. cold water. Most fish and plant species tolerate only a limited range of water temperatures: Tropical or warm water aquaria maintain an average temperature of about 25 °C (77 °F) are much more common, and tropical fish are among the most popular aquarium denizens. Cold water aquaria maintain temperatures below the room temperature. More importantly than the range is temperature consistency; most organisms are not accustomed to sudden changes in temperatures, which can cause shock and lead to disease. Water temperature can be regulated with a combined thermometer and heating or cooling unit.

Water movement can also be important in accurately simulating a natural ecosystem. Fish may prefer anything from still water up to swift, simulated currents. Water movement can be controlled through the use of aeration from air pumps, powerheads, and careful design of water flow (such as location of filtration system points of inflow and outflow).

Nitrogen cycle



The nitrogen cycle in an aquarium

Fish are animals and generate waste as they metabolize food, which aquarists must manage. Fish, invertebrates, fungi, and some bacteria excrete nitrogen in the form of ammonia (which converts to ammonium in acidic water) and must then pass through the nitrogen cycle. Ammonia is also produced through the decomposition of plant and animal matter, including fecal matter and other detritus. Nitrogen waste products become toxic to fish and other aquarium inhabitants above a certain concentration.

The process

A well-balanced tank contains organisms that metabolize the waste products of other inhabitants. Nitrogen waste is metabolized in aquaria by a type of bacteria known as nitrifiers (genus *Nitrosomonas*). Nitrifying bacteria metabolize ammonia into nitrite. Nitrite is also highly toxic to fish in high concentrations. Another type of bacteria, genus *Nitrospira*, on-converts nitrite into less-toxic nitrate. (*Nitrobacter* bacteria were previously believed to fill this role, and appear in "jump start" kits. While biologically they could theoretically fill the same niche as *Nitrospira*, it has recently been found that *Nitrobacter* are not present in detectable levels in established aquaria, while *Nitrospira* are plentiful.) This process is known in the aquarium hobby as the nitrogen cycle.

Aquatic plants also metabolize ammonia and nitrate, using it to build biomass. However, this is only temporary, as the plants release nitrogen back into the water when older leaves die off and decompose.

Maintaining the nitrogen cycle

Although called the nitrogen "cycle" by hobbyists, in aquaria the cycle is not complete: nitrogen must be added (usually indirectly through food) and nitrates must be removed at the end. Nitrogen bound up in plant matter is removed when the plant grows too large.

Hobbyist aquaria typically do not have the requisite bacteria needed to detoxify nitrogen waste. This problem is most often addressed through filtration. Activated carbon filters absorb nitrogen compounds and other toxins from the water.

Biological filters provide a medium specially designed for colonization by the desired nitrifying bacteria. Activated carbon and other substances, such as ammonia absorbing resins, stop working when their pores fill, so these components have to be replaced with fresh stocks periodically.

New aquaria often have problems associated with the nitrogen cycle due to insufficient beneficial bacteria, which is known as "New Tank Syndrome". Therefore, new tanks have to mature before stocking them with fish. There are three basic approaches to this: the *fishless cycle*, the *silent cycle*, and *slow growth*.

Tanks undergoing a "fishless cycle" have no fish. Instead, the keeper adds ammonia to feed the bacteria. During this process, ammonia, nitrite, and nitrate levels measure progress.

The "silent cycle" involves adding fast-growing plants and relying on them to consume the nitrogen, filling in for the bacteria work until their number increases. Anecdotal reports indicate that such plants can consume nitrogenous waste so efficiently that the ammonia and nitrite spikes that occur in more traditional cycling methods are greatly reduced or undetectable.

"Slow growth" entails slowly increasing the fish population over 6 to 8 weeks, giving bacteria time to grow and reach a balance with the increasing waste production.

The largest bacterial populations inhabit the filter; efficient filtration is vital. Sometimes, simply cleaning the filter is enough to seriously disturb the aquarium's balance. Best practice is to flush mechanical filters using compatible water to dislodge organic materials, while preserving bacteria populations. Another safe practice involves cleaning only one half of the filter media every time the filter or filters are serviced to allow the remaining bacteria to repopulate the cleaned half.

Tank capacity



19 Litre Aquarium

Biological loading is a measure of the burden placed on the aquarium ecosystem by its living inhabitants. Higher biological loading represents a more complicated ecology, which makes equilibrium easier to perturb. The surface area of water exposed to air limits dissolved oxygen. The population of nitrifying bacteria is limited by the available physical space.

Tank size

Fish capacity is a function of aquarium size. Limiting factors include the availability of oxygen in the water and the rate at which the filter can process waste. Aquarists apply rules of thumb estimating appropriate population size; the examples below are for small freshwater fish. Larger freshwater fish and most marine fishes need much more generous allowances. Some aquarists claim that increasing water depth beyond some relatively shallow minimum does not affect capacity.

- 1.5 of water for each centimetre of fish length (1 gallon per inch).
- 30 square centimetres of surface area per centimetre of fish length (12 square inches per inch).

Experienced aquarists warn against mechanically applying these rules because they do not consider other important issues such as growth rate, activity level, social behavior, and so on. Once the tank nears capacity, best practice is to add the remaining fish over a period of time while monitoring water quality.

The capacity can be improved by surface movement and water circulation such as through aeration, which not only improves oxygen exchange, but also the decomposition of waste materials.

Other factors

Other variables affect tank capacity. Smaller fish consume more oxygen per unit of body weight than larger fish. Labyrinth fish can breathe atmospheric oxygen and need less surface area (however, some are territorial, and do not tolerate crowding). Barbs require more surface area than tetras of comparable size. The presence of waste materials presents itself as a variable as well. Decomposition consumes oxygen, reducing the amount available for fish. Oxygen dissolves less readily in warmer water, while warmer water temperature increase fish activity levels, which in turn consume more oxygen.

Fishkeeping industry

Worldwide, the fishkeeping hobby is a multi-billion dollar industry. The United States is the largest market, followed by Europe and Japan. In 1993 the United States Census Bureau found that 10.6% of U.S. households owned ornamental freshwater or saltwater fish, with an average of 8.8 fish per household. In 1993, the retail value of the fish hobby in the United States was US\$910 million. In 2002, census data indicated that aquarium products and fish accounted for USD684 million dollars.

From 1989 to 1992, almost 79% of all U.S. ornamental fish imports came from Southeast Asia and Japan. Singapore, Thailand, the Philippines, Hong Kong, and Indonesia were the top five exporting nations. South America was the second largest exporting region, accounting for 14% of the total annual value. Colombia, Brazil and Peru were the major suppliers.

Approximately 201 million fish worth \$44.7 million were imported into the United States in 1992. These fish comprised 1,539 different species; 730 freshwater species, and 809 saltwater species. Freshwater fish accounted for approximately 96% of the total volume and 80% of the total import value. Only 32 species had import values over \$10,000. The top species were freshwater and accounted for 58% of the total imported value. The top imported species are the guppy, neon tetra, platy, betta, Chinese algae eater, and goldfish. Given 91.9 million total US households in 1990, 9.7 million are fishkeepers. 8.8 fish per household implies a total aquarium fish population of approximately 85.7 million, suggesting that the US aquarium fish population turns over more than 2.3 times per year, counting only imported fish.

Historically, fish and plants for the first modern aquaria were gathered from the wild and transported (usually by ship) to Europe and America. During the early 20th century many species of small colourful tropical fish were exported from Manaus, Brazil; Bangkok, Thailand; Jakarta, Indonesia; the Netherlands Antilles; Kolkata, India; and other tropical countries. Import of wild fish, plants, and invertebrates for aquaria continues today around the world. Many species have not been successfully bred in captivity. In many developing countries, locals survive by collecting specimens for the aquarium trade., and continue to introduce new species to the market.

Fish breeding



A Discus (*Symphysodon* spp.) guarding its eggs

Fish breeding is a challenge that attracts many aquarists. While some species reproduce freely in community tanks, most require special conditions, known as spawning triggers before they will breed. The majority of fish lay eggs, known as spawning, and the juvenile fish that emerge are very small and need tiny live food or substitutes to survive.

A fair number of popular aquarium fish are livebearers which produce a small number of relatively large offspring. These usually take ground flake food straight away.

Animal welfare

A properly maintained aquarium allows fish to socialize with their own species and in many cases breed successfully. This is in marked contrast to the conditions of larger animals like cats and dogs, which are often kept alone and neutered in an environment different from what they would experience in the wild. However, fish are often maintained in inadequate conditions. Therefore they live short lives and never breed.

Inexperienced aquarists often keep too many fish in one tank, or add fish too quickly into an immature aquarium, killing many of them. This has given the hobby a bad reputation among some animal welfare groups, such as PETA, who accuse aquarists of treating aquarium fish as cheap toys to be replaced when they die.

Goldfish and bettas in particular have often been kept in small bowls or aquaria that are too small for their needs. In some cases fish have been installed in all sorts of inappropriate objects such as the **AquaBabies Micro Aquaria**, **Bubble Gear Bubble Bag**, and **Betta in a Vase**, all of which house live fish in unfiltered and insufficient water. The latter is sometimes marketed as a complete ecosystem because a plant is included in the neck of the vase. Some sellers claim the fish eat the plant roots. However, bettas are carnivorous and need live food or pellet foods. They cannot survive on plant roots. Another problem is that the plant sometimes blocks the betta's passage to the water surface. They are labyrinth fish, and need to breathe at the surface to avoid suffocation.

Such products are aimed at people looking for a novelty gift. Aquarists actively condemn them. Similarly, the awarding of goldfish as prizes at funfairs is traditional in many parts of the world, but has been criticized by aquarists and activists as cruel and irresponsible. The United Kingdom outlawed live-animal prizes such as goldfish in 2004.

The use of live prey to feed carnivorous fish such as piranhas also draws criticism.

Fish modification

Modifying fish to make them more attractive as pets is increasingly controversial. Historically, artificially dyeing fish was common. Glassfish in particular were often injected with fluorescent dyes. The major British fishkeeping magazine, *Practical Fishkeeping*, has been effective in its campaign to remove these fish from the market by educating retailers and aquarists to the cruelty and health risks involved.

In 2006, *Practical Fishkeeping* published an article exposing the techniques for performing cosmetic surgery on aquarium fish, without anaesthesia, as described by Singaporean fishkeeping magazine *Fish Love Magazine*. The tail is cut off and dye is injected into the body. The piece also included the first documented evidence to demonstrate that parrot cichlids are injected with coloured dye. Hong Kong suppliers

were offering a service in which fish could be tattooed with company logos or messages using a dye laser; such fishes have been sold in the UK under the name of Kaleidoscope gourami and Striped parrot cichlid. Some people give their fish body piercings.

Hybrid fish such as flowerhorn cichlids and parrot cichlids are highly controversial. Parrot cichlids in particular have a very unnatural shape that prevents them from swimming properly and makes it difficult for them to engage in normal feeding and social behaviors. The biggest concern with hybrids is that they may be bred with native species, making it difficult for hobbyists to identify and breed particular species. This is especially important to hobbyists who shelter species that are rare or extinct in the wild. Extreme mutations have been selected for by some breeders; some fancy goldfish varieties in particular have features that prevent the fish from swimming, seeing, or feeding properly.

Genetically modified fish such as the GloFish are likely to become increasingly available, particularly in the United States and Asia. Although GloFish are said to be unharmed by their genetic modifications, they remain illegal in many places, including the European Union, though at least some have been smuggled into the EU, most likely from Taiwan, via the Czech Republic.

Conservation

The two main sources of fish for aquaria are from capture in the wild or captive breeding. United Nations studies show that more than 90% of freshwater aquarium fish are captive-bred, while virtually all marine fish and invertebrates are caught. The few marine species bred in captivity supplement but rarely replace the trade in wild-caught specimens. Wild-caught animals provide valuable income for people in regions lacking other high-value exports.

Marine fish are typically less resilient during transport than freshwater fish, and relatively large numbers of them die before they reach the aquarist. Although the aquarium trade probably represents a minor threat to coral reefs compared to habitat destruction, fishing for food, and climate change, it is a booming trade and may be a serious problem in specific locations such as the Philippines and Indonesia where most collecting is done. Catching fish in the wild can reduce their population sizes, placing them in danger of extinction in collecting areas, as has been observed with the dragonet *Synchiropus splendidus*.

Collecting

In theory, reef fish should be a good example of a renewable resource that encourages fishermen to maintain the integrity and diversity of the natural habitat: more and better fish can be exported from pristine habitats than those that have been polluted or over-harvested. However, this has not been the case in similar industries such as fur trapping, logging, or fishing that experience the *tragedy of the commons*.

Fish are caught by net, trap, or cyanide. Collecting expeditions can be lengthy and costly, and are not always successful. Fish can also be injured during collection and/or shipping; mortality rates during shipping are high. Many others are weakened by stress and become diseased.

Other problems include the poisoning of coral reefs and non-target species, the depletion of rare species from their natural habitat, and ecosystem degradation from large scale removal of key species. Additionally, destructive fishing techniques concern environmentalists and hobbyists alike. There has been a concerted movement to captive breeding and certification programs for wild-caught fish. Two thirds of American marine aquarists surveyed in 1997 preferred farmed coral, and over 80% think that only sustainably caught or farmed fish should be traded.

Cyanide

Cyanide is a poison that stuns and immobilizes fish. Fishers put cyanide in the ocean, to ease the process of netting them. It can irreversibly damage or kill the target fish, as well as other fish, mammals, reptiles or invertebrates that are left behind. Some UK-based wholesalers advertise that they avoid cyanide-caught animals. In the Philippines, overfishing and cyanide caused a drastic decline in aquarium fish, leading the country away from cyanide and towards netting healthy animals. Cyanide is also often used for collecting freshwater species, especially in muddy water with lots of vegetation, which complicates catching small and fast moving fish.

Captive breeding and aquaculture

Since the Siamese fighting fish (*Betta splendens*) was first successfully bred in France in 1893, captive spawning and brooding techniques used in aquaculture have slowly improved. Captive breeding for aquaria is concentrated in southern Florida, Singapore, Hong Kong and Bangkok, with smaller industries in Hawaii and Sri Lanka. Captive breeding of marine organisms has been in development since the mid-1990s. Breeding for freshwater species is more advanced than for saltwater species. Currently, only a few captive-bred marine species are in the trade, including clownfish, damselfish, and dwarf angelfish.

Aquaculture can help in lessening the impacts on wild stocks, either by using cultivated organisms for sale or by releasing them to replenish wild stocks. Breeding programs help preserve species that have become rare or extinct in the wild, most notably the Lake Victoria cichlids.

Some species have also become important as laboratory animals. Cichlids and poecilids are especially important for studies on learning, mating, and social behavior. Hobbyists also keep and observe many fishes not otherwise studied, and thereby provide valuable ecological and behavioral data.

Captive breeding has reduced prices for hobbyists, but cultured animals remain more expensive. Selective breeding has also led to wider intra–species variation, creating more diverse commercial stocks.

Invasive species

Serious problems can occur when fish originally raised in ponds or aquaria are released into the wild. While tropical fish do not survive in temperate climates, they can thrive in waters that are similar to their native habitat. Non–native species that become established are called exotic species. Freshwater examples include various cichlids in Florida, goldfish in temperate waters, and South American suckermouth catfishes in warm waters around the world. Invasive species can seriously disrupt their new homes by preying on, or competing with, native species. Many marine fish have also been introduced into non-native waters, disrupting the local habitat.

Humane treatment

In January 2011 the Maui County Council just passed measure requiring the aquarium fishery to adopt humane practices for preparing fish for transport to market. The regulations control harvesting and shipping practices, including prohibiting clipping the fins on fish to protect the plastic shipping bags, outlawing puncturing swim bladders that fish use to regulate their buoyancy, which enabled divers to rapidly surface and prohibiting "starving" the fish which permitted smaller shipping bags without killing the fish with their own waste. The measure also requires that shippers file mortality reports on the animals they ship.

Recreational fishing



Girl with her catch

Recreational fishing, also called **sport fishing**, is fishing for pleasure or competition. It can be contrasted with commercial fishing, which is fishing for profit, or subsistence fishing, which is fishing for survival.

The most common form of recreational fishing is done with a rod, reel, line, hooks and any one of a wide range of baits. Other devices, commonly referred to as *terminal tackle*, are also used to affect or complement the presentation of the bait to the targeted fish. Some examples of terminal tackle include weights, floats, and swivels. Lures are frequently used in place of bait. Some hobbyists make handmade tackle themselves, including plastic lures and artificial flies. The practice of catching or attempting to catch fish with a hook is known as angling. When angling, it is sometimes expected or required that the fish be released.

Big-game fishing is fishing from boats to catch large open-water species such as tuna, sharks and marlin. Noodling and trout tickling are also recreational activities. One method of growing popularity is kayak fishing. Kayak fishermen fish from sea kayaks in an attempt to level the playing field with fish and to further challenge their abilities. Kayaks are stealthy and allow anglers to reach areas not fishable from land or by conventional boat. Sport fishing is dominated by men, although women also participate in the sport.

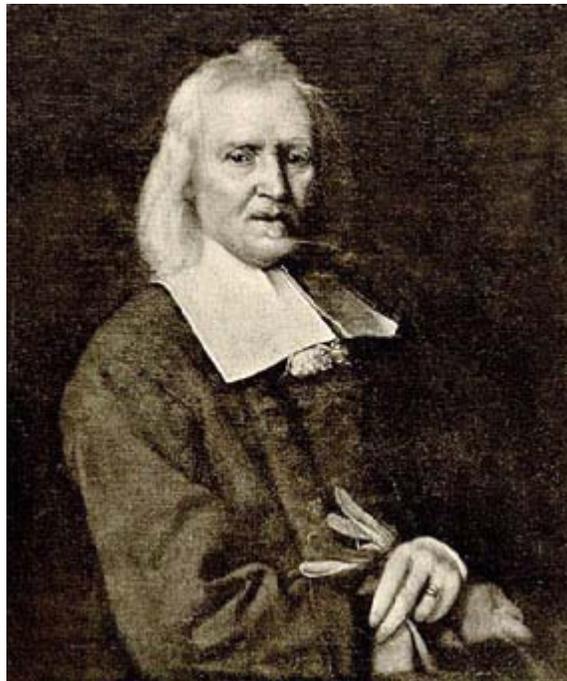
History

The earliest English essay on recreational fishing was published in 1496, shortly after the invention of the printing press. The authorship of this was attributed to Dame Juliana Berners, the prioress of the Benedictine Sopwell Nunnery. The essay was titled *Treatyse of Fysshynge wyth an Angle*, and was published in the second *Boke of St Albans*, a treatise on hawking, hunting and heraldry. These were major interests of the nobility, and the publisher, Wynkyn de Worde, was concerned that the book should be kept from those who were not gentlemen, since their immoderation in angling might "utterly destroy it".

During the 16th century the work was much read, and was reprinted many times. *Treatyse* includes detailed information on fishing waters, the construction of rods and lines, and the use of natural baits and artificial flies. It also includes modern concerns about conservation and angler etiquette.



Sketch of Juliana Berners

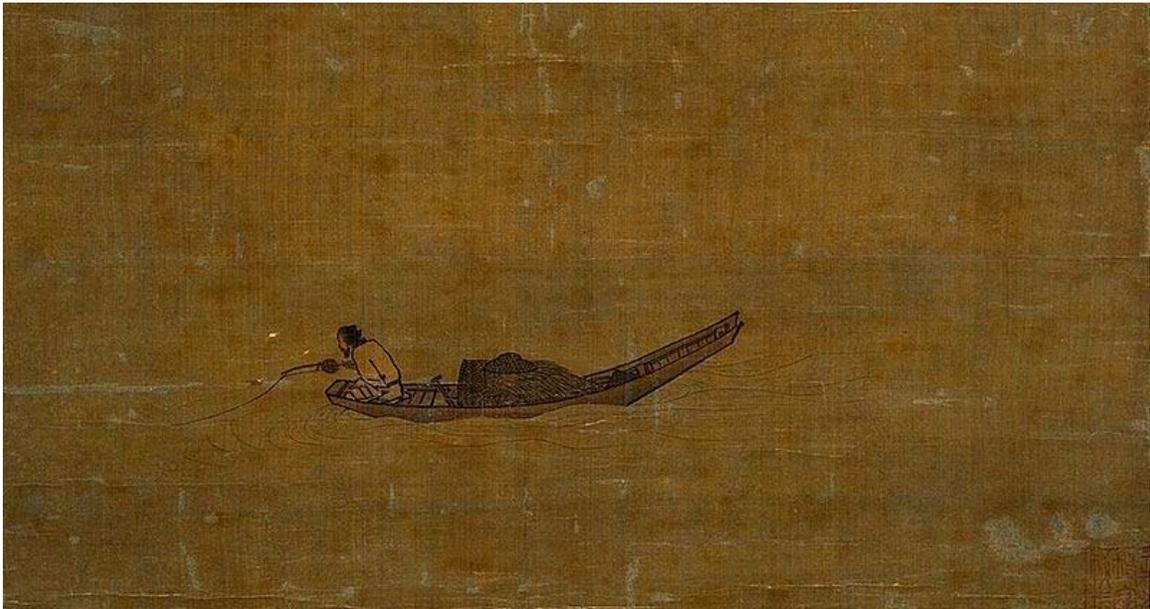


Izaak Walton



C.F. Holder, 1898
183 lb. Bluefin Tuna

Charles F. Holder with his then record 183lb. bluefin tuna catch, 1898.



"Angler on a Wintry Lake," painted in 1195 by Ma Yuan, Chinese Song Dynasty, featuring the oldest known depiction of a fishing reel.

Recreational fishing for sport or leisure gained popularity during the 16th and 17th centuries, and coincides with the publication of Izaak Walton's *The Compleat Angler, or Contemplative Man's Recreation* in 1653. This book is the definitive work that champions the position of the angler who loves fishing for the sake of fishing.

More than 300 editions of *The Compleat Angler* have been published. The pastoral discourse is enriched with country fishing folklore, songs and poems, recipes and anecdotes, moral meditations and quotes from classic literature. The central character, Piscator, champions the art of angling, but also tranquilly relishes the pleasures of friendship, verse and song, good food and drink.

The early evolution of fishing as recreation is not clear. For example, there is anecdotal evidence for fly fishing in Japan as early as the ninth century BCE, and in Europe Claudius Aelianus (175–235 CE) describes fly fishing in his work *On the Nature of Animals*, as

"a Macedonian way of catching fish... They fasten red (crimson red) wool round a hook, and fix on to the wool two feathers which grow under a cock's wattles, and which in colour are like wax. Their rod is six feet long, and their line is the same length. Then they throw their snare, and the fish, attracted and maddened by the colour, comes straight at it..."

But for the early Japanese and Macedonians, fly fishing was likely to have been a means of survival, rather than recreation. It is possible that antecedents of recreational fly fishing arrived in England with the Norman conquest of 1066. Although the point in history where fishing could first be said to be recreational is not clear, it is clear that recreational fishing had fully arrived with the publication of *The Compleat Angler*.

Big-game fishing started as a sport after the invention of the motorized boat. In 1898, Dr. Charles Frederick Holder, a marine biologist and early conservationist, invented this sport and went on to publish many articles and books on the subject noted for their combination of accurate scientific detail with exciting narratives.

Sport fishing



Common aluminum bass boat used for fresh water fishing

Sport fishing methods vary according to the area fished, the species targeted, the personal strategies of the angler, and the resources available. It ranges from the aristocratic art of fly fishing elaborated in Great Britain, to the high-tech methods used to chase marlin and tuna. Sport fishing is usually done with hook, line, rod and reel rather than with nets or other aids.

The most common salt water game fish are marlin, tuna, tarpon, sailfish, shark, and mackerel.

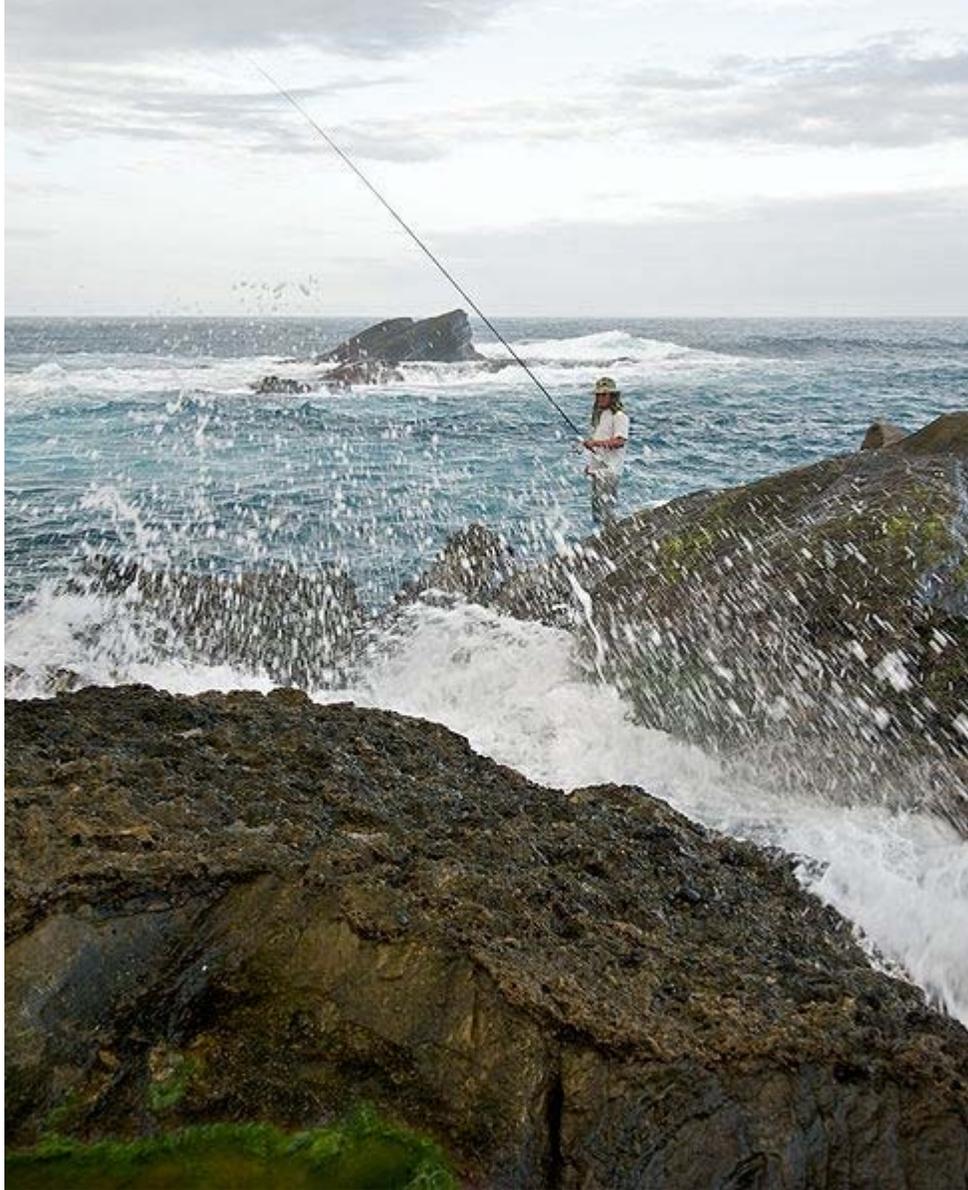
In North America, freshwater fish include snook, redfish, salmon, trout, bass, pike, catfish, walleye and muskellunge. The smallest fish are called panfish, because they can fit in a normal cooking pan. Examples are crappies, perch, rock bass, bluegill and sunfish.

In the past, sport fishers, even if they did not eat their catch, almost always killed them to bring them to shore to be weighed or for preservation as trophies. In order to protect recreational fisheries sport fishermen now often catch and release, and sometimes tag and release, which involves fitting the fish with identity tags, recording vital statistics, and sending a record to a government agency.

Fishing techniques



Fisherman at Lake Merced is using a rod



Rock fishing at Shihtiping in Taiwan

Recreational fishing techniques include hand gathering, spearfishing, netting, angling and trapping.

Most recreational fishers use a fishing rod with a fishing line and a hook at the end of the line. The rod may be equipped with a reel so the line can be reeled in, and some form of bait or a lure attached to the hook. Fly fishing is a special form of rod fishing in which the reel is attached to the back end of the rod, and a whipping motion is used to imitate a fly with an artificial fly. Another less common technique is bowfishing using a regular bow or a crossbow. The "arrow" is a modified bolt with barbs at the tip, connected to a fishing line so the fish can be retrieved. Some crossbows are fitted with a reel.

The effective use of fishing techniques often depends on knowledge about the fish and their behaviour including migration, foraging and habitat.

Fishing tackle

Fishing tackle is a general term that refers to the equipment used by fishers. Almost any equipment or gear used for fishing can be called fishing tackle. Some examples are hooks, lines, sinkers, floats, rods, reels, baits, lures, spears, nets, gaffs, traps, waders and tackle boxes.

Tackle that is attached to the end of a fishing line is called **terminal tackle**. This includes hooks, sinkers, floats, leaders, swivels, split rings and wire, snaps, beads, spoons, blades, spinners and clevises to attach spinner blades to fishing lures.

Fishing tackle can be contrasted with fishing techniques. Fishing tackle refers to the physical equipment that is used when fishing, whereas fishing techniques refers to the ways the tackle is used when fishing.

Rules and regulations

Recreational fishing has conventions, rules, licensing restrictions and laws that limit the way in which fish may be caught. The International Game Fish Association (IGFA) makes and oversees a set of voluntary guidelines. Typically, these prohibit the use of nets and the catching of fish with hooks not in the mouth. Enforceable regulations are put in place by governments to ensure sustainable practice amongst anglers. For example in the Republic of Ireland, the Central Fisheries Board oversees the implementation of all angling regulations, which include controls on angling lures, baits and number of hooks permissible, as well as licensing regimes and other conservation based restrictions.

Fish logs

In addition to capturing fish for food, recreational anglers may also keep a log of fish caught and submit trophy-sized fish to independent record keeping bodies. In the Republic of Ireland, the Irish Specimen Fish Committee verifies and publicizes the capture of trophy fish caught with rod and line by anglers in Ireland, both in freshwater and at sea. The Committee also ratifies Irish record rod caught fish. It also uses a set of 'fair play' regulations to ensure fish are caught in accordance with accepted angling norms.

Competitions

Recreational fishing competitions (tournaments) are a recent innovation in which fishermen compete for prizes based on the total weight of a given species of fish caught within a predetermined time. This sport evolved from local fishing contests into large competitive circuits, especially in North America. Competitors are most often professional fishermen who are supported by commercial endorsements. Other

competitions are based purely on length with mandatory catch and release. Either longest fish or total length is documented with a camera and a mandatory sticker or unique item, a practice used since it's hard to weigh a living fish accurately in a boat.

Sport fishing competitions involve individuals if the fishing occurs from land, and usually teams if conducted from boats, as well as specified times and areas for catching fish. A score is awarded for each fish caught. The points awarded depend on the fish's weight and species. Occasionally a score is divided by the strength of the fishing line used, yielding more points to those who use thinner, weaker line. In tag and release competitions, a flat score is awarded per fish species caught, divided by the line strength. Usually sport fishing competitions award a prize to the boat or team with the most points earned.

In Australia, a self-administered standard for the environmental assessment of tournament fishing has been proposed as an alternative and possible pathway to the ISO 14001 international standard. The standard assesses environmental, social, economic, and public risk factors. Tournament organizers may apply for voluntary certification. In some US states, fishery agencies and competition organizers create their own codes of practice.

Industry

The recreational fishing industry consists of enterprises such as the manufacture and retailing of fishing tackle, the design and building of recreational fishing boats, and the provision of fishing boats for charter and guided fishing trips.

"Pay to fish" enterprises provide anglers with controlled access to stocked lakes, ponds or canals. These provide fishing opportunities outside of the permitted seasons and quotas applied to public waters. In the United Kingdom, commercial fisheries of this sort charge access fees. In North America, establishments usually charge for the fish caught, by length or by weight, rather than for access to the site although some establishments charge both types of fees.

Recreational fishing is a multi-billion dollar industry In the USA, about 12 million recreational saltwater fishers generate \$30 billion in economic impact and support 350,000 jobs.

Angling



Angling with a rod

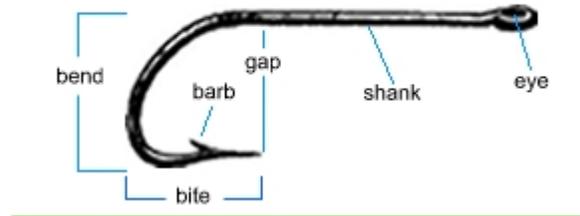
Angling is a method of fishing by means of an "angle" (fish hook). The hook is usually attached to a fishing line and the line is often attached to a fishing rod. Fishing rods are usually fitted with a fishing reel that functions as a mechanism for storing, retrieving and paying out the line. The hook itself can be dressed with lures or bait. A bite indicator such as a float is sometimes used.

Angling is a principal method of sport fishing, but commercial fisheries also use angling methods such as longlining or trolling. Catch and release fishing is increasingly practiced by recreational fishermen. In many parts of the world, size limits apply to certain species, meaning fish below and/or above a certain size must, by law, be released.

Introduction

The species of fish pursued by anglers vary with geography. Among the many species of salt water fish that are caught for sport are swordfish, marlin, tuna, salmon and halibut. In North America, the most popular fresh water sport species include bass, pike, walleye, muskellunge, yellow perch, trout, salmon, catfish, crappie, bluegill and sunfish. In Europe, a large number of anglers fish for species such as carp, pike, tench, rudd, roach, European perch and barbel (especially in stillwaters). Although some fish are sought for their value as food, others are pursued for their fighting abilities or for the difficulty of pursuit.

Hooks



A fish hook.

The use of the hook in angling is descended, historically, from what would today be called a "gorge." The word "gorge", in this context, comes from the French word meaning "throat." Gorges were used by ancient peoples to capture fish. A gorge was a long, thin piece of bone or stone attached by its midpoint to a thin line. The gorge would be fixed with a bait so that it would rest parallel to the lay of the line. When a fish would swallow the bait, a tug on the line would cause the gorge to orient itself at right angles to the line, thereby sticking in the fish's gullet.

Baits

Which of the various techniques an angler may choose is dictated mainly by the target species and by its habitat. Angling can be separated into two main categories: using either artificial or natural baits.



Green Highlander, an artificial fly used for salmon fishing.

Artificial baits

Many people prefer to fish solely with lures, which are artificial baits designed to entice fish to strike. The artificial bait angler uses a man-made lure that may or may not represent prey. The lure may require a specialised presentation to impart an enticing action as, for example, in fly fishing. A common way to fish a soft plastic worm is the Texas Rig.

Natural baits



The rat-tailed maggot is a popular fish bait

The natural bait angler, with few exceptions, will use a common prey species of the fish as an attractant. The natural bait used may be alive or dead. Common natural baits include worms, leeches, minnows, frogs, salamanders, and insects. Natural baits are effective due to the lifelike texture, odour and colour of the bait presented.

The common earthworm is a universal bait for fresh water angling. Grubs and maggots are also excellent bait when trout fishing. Grasshoppers, bees and even ants are also used as bait for trout in their season, although many anglers believe that trout or salmon roe is superior to any other bait. In lakes in southern climates such as Florida, USA, fish such as bream will take bread bait. Bread bait is a small amount of bread, often moistened by saliva, balled up to a small size that is bite size to small fish.

Roe is an excellent bait for trout, salmon and many other fresh water fish.

Spreading disease



Fathead minnow — a common bait fish

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 alien to the ecosystem.

Laws and regulations



An angler on the Kennet and Avon Canal, England, displays his catch.

Laws and regulations managing angling vary greatly, often regionally, within countries. These commonly include permits (licences), closed periods (seasons) where specific species are unavailable for harvest, restrictions on gear types, and quotas.

Laws generally prohibit catching fish with hooks other than in the mouth (foul hooking, "snagging" or "jagging") or the use of nets other than as an aid in landing a captured fish. Some species, such as bait fish, may be taken with nets, and a few for food. Sometimes, (non-sport) fish are considered of lesser value and it may be permissible to take them by methods like snagging, bow and arrow, or spear. None of these techniques fall under the definition of angling since they do not rely upon the use of a hook and line.

Fishing seasons

Fishing seasons are set by countries or localities to indicate what kinds of fish may be caught during sport fishing (also known as angling) for a certain period of time. Fishing seasons are enforced to maintain ecological balance and to protect species of fish during their spawning period during which they are easier to catch.

Catch and release

Although most anglers keep their catch for consumption, catch and release fishing is increasingly practiced, especially by fly anglers. The general principle is that releasing fish allows them to survive, thus avoiding unintended depletion of the population. For species such as marlin and muskellunge but, also, among few bass anglers, there is a cultural taboo against killing fish for food. In many parts of the world, size limits apply to certain species, meaning fish below a certain size must, by law, be released. It is generally believed that larger fish have a greater breeding potential. Some fisheries have a slot limit that allows the taking of smaller and larger fish, but requiring that intermediate sized fish be released. It is generally accepted that this management approach will help the fishery create a number of large, trophy-sized fish. In smaller fisheries that are heavily fished, catch and release is the only way to ensure that catchable fish will be available from year to year.



Removing the hook from a Bonito

The practice of catch and release is criticised by some who consider it unethical to inflict pain upon a fish for purposes of sport. Some of those who object to releasing fish do not object to killing fish for food. Adherents of catch and release dispute this charge, pointing out that fish commonly feed on hard and spiky prey items, and as such can be expected to have tough mouths, and also that some fish will re-take a lure they have just been hooked on, a behaviour that is unlikely if hooking were painful. Opponents of catch and release fishing would find it preferable to ban or to severely restrict angling. On the other hand, proponents state that catch-and-release is necessary for many fisheries to remain sustainable, is a practice that generally has high survival rates, and consider the banning of angling as not reasonable or necessary.

In some jurisdictions, in the Canadian province of Manitoba, for example, catch and release is mandatory for some species such as brook trout. Many of the jurisdictions which mandate the live release of sport fish also require the use of artificial lures and barbless hooks to minimise the chance of injury to fish. Mandatory catch and release also

exists in the Republic of Ireland where it was introduced as a conservation measure to prevent the decline of Atlantic salmon stocks on some rivers. In Switzerland, catch and release fishing is considered inhumane and was banned in September 2008.

Barbless hooks, which can be created from a standard hook by removing the barb with pliers or can be bought, are sometimes resisted by anglers because they believe that increased escapement results. Barbless hooks reduce handling time, thereby increasing survival. Concentrating on keeping the line taut while fighting fish, using recurved point or "triple grip" style hooks on lures, and equipping lures that do not have them with split rings can significantly reduce escapement.

Capacity for pain



Rainbow trout

Animal protection advocates have raised concerns about the possible suffering of fish caused by angling. In light of recent research, some countries, like Germany, have banned specific types of fishing and the British RSPCA now formally prosecutes individuals who are cruel to fish.

Experiments done by William Tavolga provide evidence that fish have pain and fear responses. For instance, in Tavolga's experiments, toadfish grunted when electrically shocked and over time they came to grunt at the mere sight of an electrode. Additional tests conducted at both the University of Edinburgh and the Roslin Institute, in which bee venom and acetic acid was injected into the lips of rainbow trout, resulted in fish rubbing their lips along the sides and floors of their tanks, which the researchers believe was an effort to relieve themselves of pain. One researcher argues about the definition of pain used in the studies.

In 2003, Scottish scientists at the University of Edinburgh performing research on rainbow trout concluded that fish exhibit behaviors often associated with pain, and the brains of fish fire neurons in the same way human brains do when experiencing pain. James D. Rose of the University of Wyoming critiqued the study, claiming it was flawed, mainly since it did not provide proof that fish possess "conscious awareness, particularly a kind of awareness that is meaningfully like ours". Rose argues that since the fish brain is rather different from ours, fish are probably not conscious (in the manner humans are), whence reactions similar to human reactions to pain instead have other causes. Rose had published his own opinion a year earlier arguing that fish cannot feel pain as they lack the appropriate neocortex in the brain. However, animal behaviorist Temple Grandin argues

that fish could still have consciousness without a neocortex because "different species can use different brain structures and systems to handle the same functions."

Tournaments and derbies

Sometimes considered within the broad category of angling is where contestants compete for prizes based on the total length or weight of a fish, usually of a pre-determined species, caught within a specified time (fishing tournaments). Such contests have evolved from local fishing contests into large competitive circuits, where professional anglers are supported by commercial endorsements. Professional anglers are not engaged in commercial fishing, even though they gain an economic reward. Similar competitive fishing exists at the amateur level with fishing derbies. In general, derbies are distinguished from tournaments; derbies normally require fish to be killed. Tournaments normally deduct points if fish can not be released alive.

Motivation



Angling at Shihtiping in Taiwan

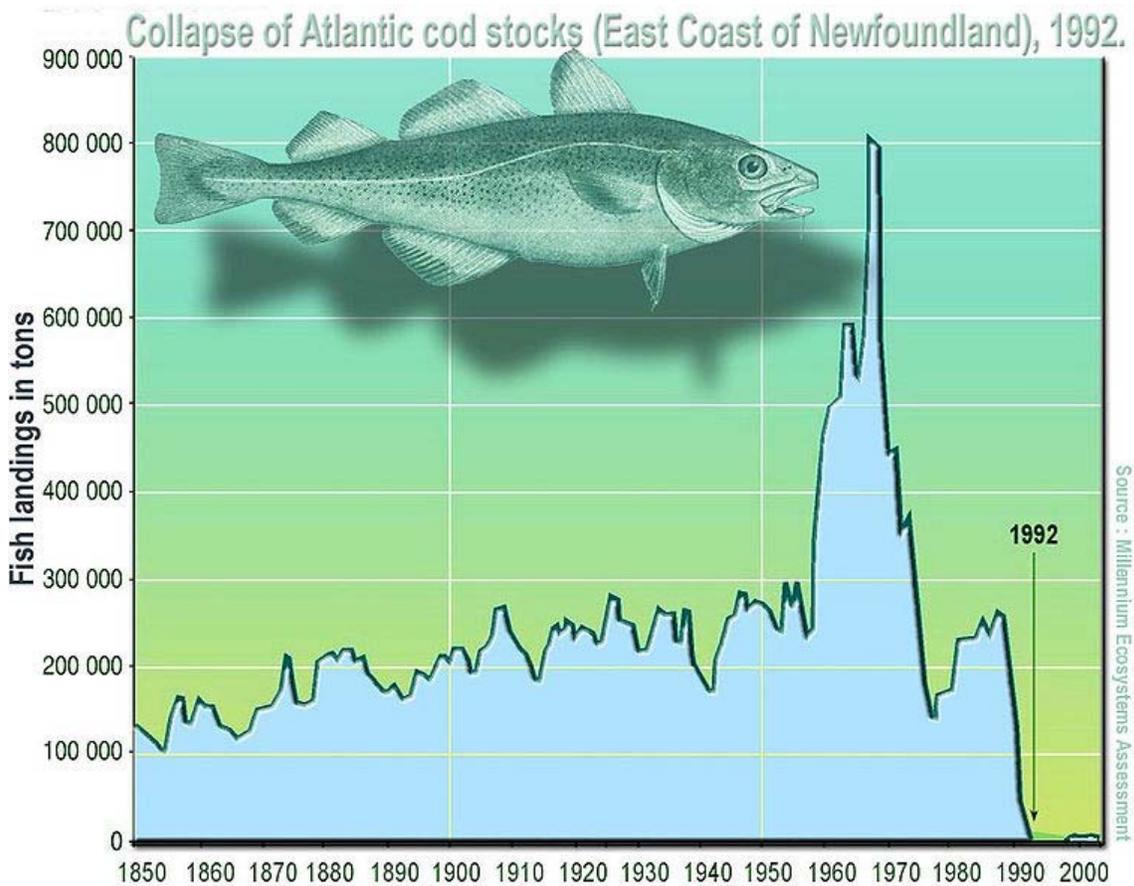
A ten-year-long survey of US fishing club members, completed in 1997, indicated that motivations for recreational angling have shifted from relaxation, an outdoor experience and the experience of the catch, to the importance of family recreation. Anglers with higher family incomes fished more frequently and were less concerned about obtaining fish as food.

A German study indicated that satisfaction derived from angling was not dependent on the actual catch, but depended more on the angler's expectations of the experience.

A 2006 study by the Louisiana Department of Wildlife and Fisheries tracked the motivations of anglers on the Red River. Included among the most often stated responses were the fun of catching fish, the experience, to catch a lot of fish or a very large fish, for challenge, adventure and more. Use as food was not investigated as a motivation for angling,

Chapter- 6

Overfishing



Atlantic cod stocks were severely overfished in the 1970s and 1980s, leading to their abrupt collapse in 1992

Overfishing occurs when fishing activities reduce fish stocks below an acceptable level. This can occur in any body of water from a pond to the oceans.

Ultimately overfishing can lead to resource depletion in cases of subsidised fishing, low biological growth rates and critical low biomass levels (e.g. by critical depensation)

growth properties). For example, overfishing of sharks has led to the upset of entire marine ecosystems.

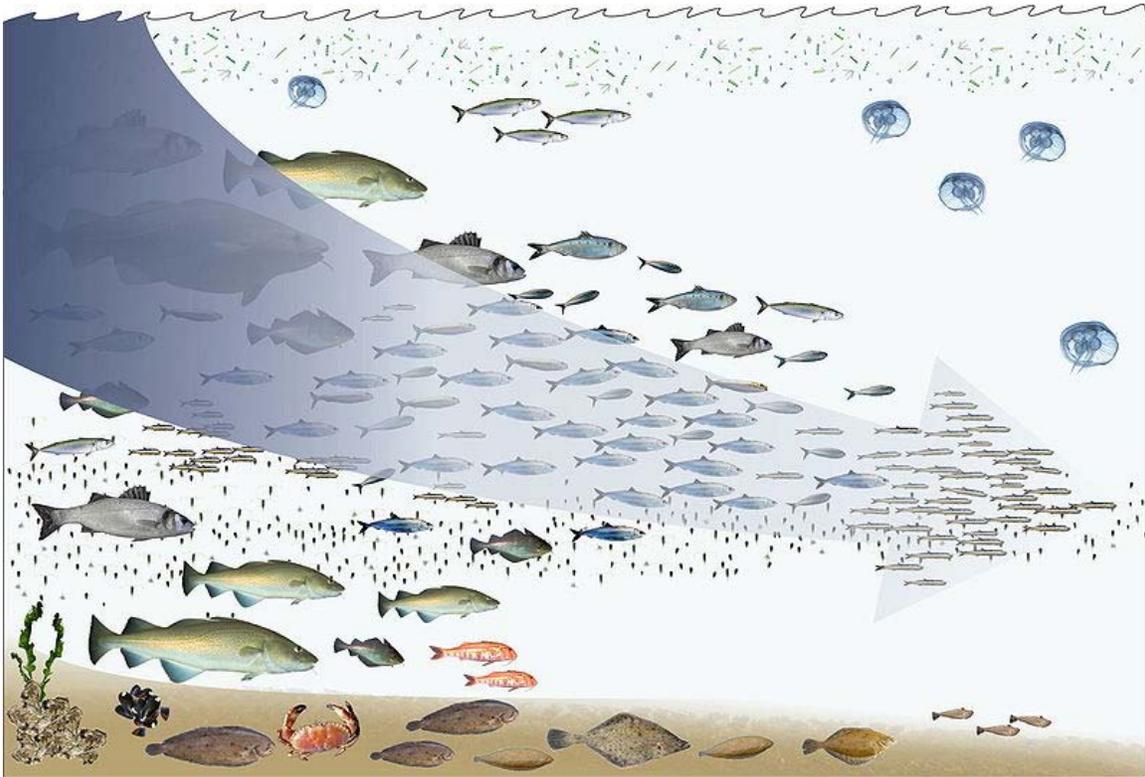
The ability of a fishery to recover after overfishing depends on whether the ecosystem conditions are suitable for the recovery. Dramatic changes in species composition can result in an ecosystem shift, where other equilibrium energy flows involve species compositions other than those that had been present before. For example, once trout have been overfished, carp might take over in a way that makes it impossible for the trout to re-establish a breeding population.

Types

There are three recognized types of overfishing: growth overfishing, recruit overfishing and ecosystem overfishing.

- Growth overfishing – is when fish are harvested at an average size that is smaller than the size that would produce the maximum yield per recruit. This makes the total yield less than it would be if the fish were allowed to grow to a reasonable size. It can be countered by reducing fishing mortality to lower levels and increasing the average size of the fish harvested to a length that will allow maximum yield per recruit.
- Recruit overfishing – is when the mature adult (spawning biomass) population is depleted to a level where it no longer has the reproductive capacity to replenish itself. There are not enough adults to produce offspring. Increasing the spawning stock biomass to a target level is the approach taken by managers to restore an overfished population to sustainable levels. This is generally accomplished by placing moratoriums, quotas and minimum size limits on a fish population.
- Ecosystem overfishing – is when the balance of the ecosystem is altered due to overfishing. Declines in the abundances of large predatory species declines and in turn small forage type species increase in abundance, causing a shift in the balance of the ecosystem towards smaller species of fish.

Instances



Fishing down the food web

Examples of the outcomes from overfishing exist in areas such as the North Sea of Europe, the Grand Banks of North America and the East China Sea of Asia. In these locations, overfishing has not only proved disastrous to fish stocks but also to the fishing communities relying on the harvest. Like other extractive industries such as forestry and hunting, fishery is susceptible to economic interaction between ownership or stewardship and sustainability, otherwise known as the tragedy of the commons.

- The Peruvian coastal anchovy fisheries crashed in the 1970s after overfishing, following an El Niño season which largely depleted anchovies from its waters. Anchovies had previously been a major natural resource in Peru; indeed, 1971 alone yielded 10.2 million metric tons of anchovies. However, in the following year, and the four after that, the Peruvian fleet's catch amounted to only about 4 million tons. This was a major loss to Peru's economy.
- The collapse of the cod fishery off Newfoundland, and the 1992 decision by Canada to impose an indefinite moratorium on the Grand Banks, is a dramatic example of the consequences of overfishing.
- The sole fisheries in the Irish Sea, the west English Channel, and other locations have become overfished to the point of virtual collapse, according to the UK government's official Biodiversity Action Plan. The United Kingdom has created

elements within this plan to attempt to restore this fishery, but the expanding global human population and the expanding demand for fish has reached a point where demand for food threatens the stability of these fisheries, if not the species' survival.

- Many deep sea fish are at risk, such as orange roughy, Patagonian toothfish and sablefish. The deep sea is almost completely dark, near freezing and has little food. Deep sea fish grow slowly because of limited food, have slow metabolisms, low reproductive rates, and many don't reach breeding maturity for 30 to 40 years. A fillet of orange roughy at the store is probably at least 50 years old. Most deep sea fish are in international waters, where there are no legal protections. Most of these fish are caught by deep trawlers near seamounts, where they congregate because of food. Flash freezing allows the trawlers to work for days at a time, and modern fishfinders target the fish with ease.

Consequences

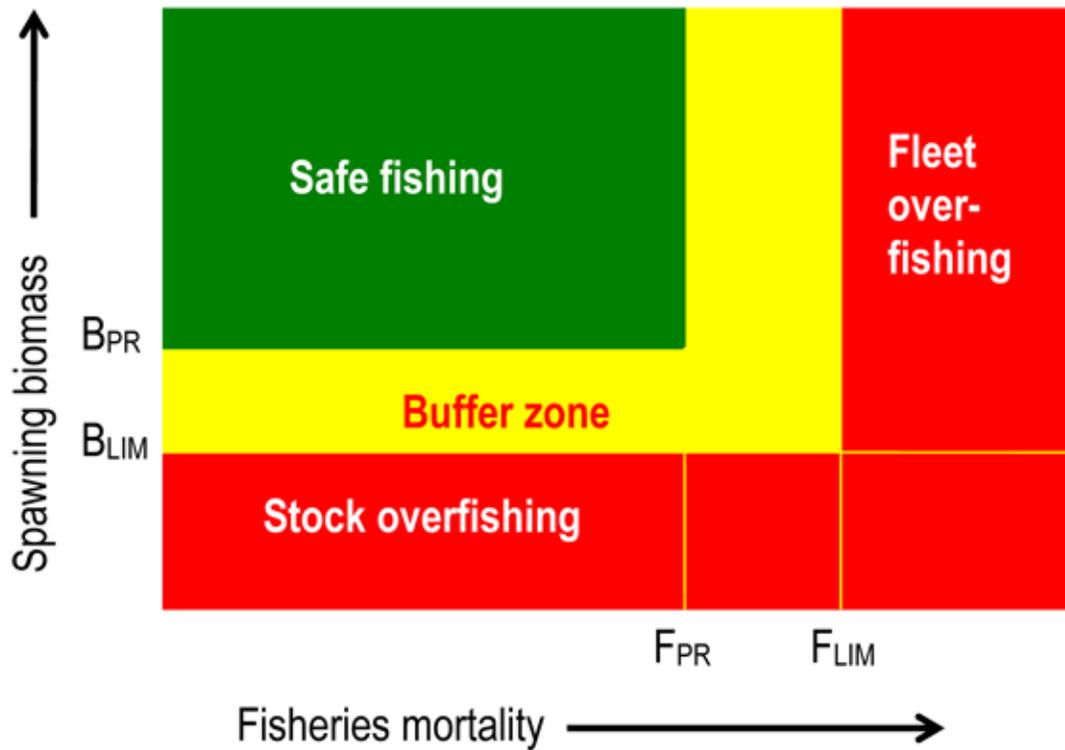
According to a 2008 UN report, the world's fishing fleets are losing \$50 billion USD each year through depleted stocks and poor fisheries management. The report, produced jointly by the World Bank and the UN Food and Agriculture Organization (FAO), asserts that half the world's fishing fleet could be scrapped with no change in catch. In addition, the biomass of global fish stocks have been allowed to run down to the point where it is no longer possible to catch the amount of fish that could be caught. Increased incidence of schistosomiasis in Africa has been linked to declines of fish species that eat the snails carrying the disease-causing parasites. Massive growth of jellyfish populations threaten fish stocks, as they compete with fish for food, eat fish eggs, and poison or swarm fish, and can survive in oxygen depleted environments where fish cannot; they wreak massive havoc on commercial fisheries. Overfishing eliminates a major jellyfish competitor and predator exacerbating the jellyfish population explosion.

Acceptable levels

The notion of overfishing hinges on what is meant by an **acceptable level** of fishing. More precise biological and bioeconomic terms define acceptable level as follows:

- **Biological overfishing** occurs when fishing mortality has reached a level where the stock biomass has negative marginal growth (slowing down biomass growth), as indicated by the red area in the figure. (Fish are being taken out of the water so quickly that the replenishment of stock by breeding slows down. If the replenishment continues to slow down for long enough, replenishment will go into reverse and the population will decrease.)
- **Economic or bioeconomic overfishing** additionally considers the cost of fishing when determining acceptable catches. Under this framework a fishery is considered to be overfished when catches exceed maximum economic yield where resource rent is at its maximum. Fish are being removed from the fishery

so quickly that the profitability of the fishery is sub-optimal. A more dynamic definition of **economic overfishing** also considers the present value of the fishery using a relevant discount rate to maximise the flow of resource rent over all future catches.



The Traffic Light colour convention, showing the concept of Harvest Control Rule (HCR), specifying when a rebuilding plan is mandatory in terms of precautionary and limit reference points for spawning biomass and fishing mortality rate.

Harvest control rule

A current model for predicting acceptable levels is the Harvest Control Rule (HCR), which is a variable over which management has some direct control as a function of some indicator of stock status. Constant catch and constant fishing mortality are two types of simple harvest control rules.

Input and output orientations

Fishing capacity can also be defined following an input or an output orientation.

- An input-oriented fishing capacity is defined as the maximum available capital stock in a fishery that is fully utilized at the maximum technical efficiency in a given time period, given resource and market conditions.

- An output-oriented fishing capacity is defined as the maximum catch a vessel (fleet) can produce if inputs are fully utilized given the biomass, the fixed inputs, the age structure of the fish stock, and the present stage of technology.

Technical efficiency of each vessel of the fleet is assumed necessary to attain this maximum catch. The degree of capacity utilization results from the comparison of the actual level of output (input) and the capacity output (input) of a vessel or a fleet.

Mitigation

With present and forecast levels of the world population it is not possible to solve the overfishing issue; however, there are mitigation measures that can save selected fisheries and forestall the collapse of others.

In order to meet the problems of overfishing, a precautionary approach and Harvest Control Rule (HCR) management principles have been introduced in the main fisheries around the world. The Traffic Light colour convention introduces sets of rules based on predefined critical values, which could be adjusted as more information is gained.

The "United Nations Convention on the Law of the Sea" treaty deals with aspects of **overfishing** in articles 61, 62, and 65.

- Article 61 requires all coastal states to ensure that the maintenance of living resources in their exclusive economic zones is not endangered by over-exploitation. The same article addresses the maintenance or restoration of populations of species above levels at which their reproduction may become seriously threatened.
- Article 62 provides that coastal states: "shall promote the objective of optimum utilization of the living resources in the exclusive economic zone without prejudice to Article 61"
- Article 65 provides generally for the rights of, inter alia, coastal states to prohibit, limit, or regulate the exploitation of marine mammals.

Overfishing can be viewed as a case of the tragedy of the commons; in that sense, solutions would promote property rights, such as privatization and fish farming. Daniel K. Benjamin, in *Fisheries are Classic Example of the "Tragedy of the Commons"*, cites research by Grafton, Squires, and Fox to support the idea that privatization can solve the overfishing problem:

Another possible solution, at least for some areas, is fishing quotas, so fishermen can only legally take a certain amount of fish. A more radical possibility is declaring certain areas of the sea "no-go zones" and make fishing there strictly illegal, so the fish in that area have time to recover and repopulate.

Controlling consumer behavior and demand is a key in mitigating action. Worldwide a number of initiatives emerged to provide consumers with information regarding the conservation status of the seafood available to them. The Guide to Good Fish Guides lists a number of these.

Fishing quotas

A model of the interaction between fish and fishers showed that when an area is closed to fishers, but there are no catch regulations such as individual transferable quotas, fish catches are temporarily increased but overall fish biomass is reduced, resulting in the opposite outcome than the one desired for fisheries. Thus, a displacement of the fleet from one locality to another will generally have little effect if the same quota is taken. As a result, management measures such as temporary closures or establishing a Marine Protected Area of fishing areas are ineffective when not combined with individual fishing quotas. An inherent problem with quotas is that fish populations vary from year to year. A study has found that fish populations rise dramatically after stormy years due to more nutrients reaching the surface and therefore greater primary production. To fish sustainably quotas need to be changed each year to take account of the population of fish but this is difficult to do.

Individual transferable quotas

Individual transferable quotas (ITQs) are fishery rationalization instruments defined under the Magnuson-Stevens Fishery Conservation and Management Act as limited access permits to harvest quantities of fish. Fisheries scientists decide the optimal amount of fish (total allowable catch) to be harvested in a certain fishery, taking into account carrying capacity, regeneration rates and future values. Under ITQs, members of a fishery are granted rights to a percentage of the total allowable catch which can be harvested each year. These quotas can be fished, bought, sold, or leased allowing for the least cost vessels to be used. ITQs are used in New Zealand, Australia, Iceland, Canada and the United States. Only three ITQ programs have been implemented in the United States due to a moratorium supported by Ted Stevens.

In 2008 a large scale study of fisheries that used ITQ's and ones that didn't provided strong evidence that ITQ's can help to prevent collapses and restore fisheries that appear to be in decline.

Fishing suspension

China bans fishing in the South China Sea for a period each year.

Benefits of underfishing

Deliberately underfishing to increase long term fish stocks has been proposed as a way fisherman can maximize their yields in the long run.

Resistance from fishermen

There is always disagreement between fishermen and government scientists... Imagine an overfished area of the sea in the shape of a hockey field with nets at either end. The few fish left therein would gather around the goals because fish like structured habitats. Scientists would survey the entire field, make lots of unsuccessful hauls, and conclude that it contains few fish. The fishermen would make a beeline to the goals, catch the fish around them, and say the scientists do not know what they are talking about. The subjective impression the fishermen get is always that there's lots of fish - because they only go to places that still have them... fisheries scientists survey and compare entire areas, not only the productive fishing spots. – *Fisheries scientist Daniel Pauly*

- The fishing capacity problem is not only related to the conservation of fish stocks but also to the sustainability of fishing activity. Causes of the fishing problem can be found in property rights regime of fishing resources. Overexploitation and rent dissipation of fishermen arise in open-access fisheries as was shown in Gordon.
- In open-access resources like fish stocks, in the absence of a system like individual transferable quotas, the impossibility of excluding others provokes the fishermen who want to increase catch to do so effectively by taking someone else's share, intensifying competition. This tragedy of the commons provokes a capitalization process that leads them to increase their costs until they are equal to their revenue, dissipating their rent completely.

Removal of subsidies

Several scientists have called for an end to subsidies paid to deep sea fisheries. In international waters beyond the 200 nautical mile exclusive economic zones of coastal countries, many fisheries are unregulated, and fishing fleets plunder the depths with state of the art technology. In a few hours, massive nets weighing up to 15 tons, dragged along the bottom by deep-water trawlers, can destroy deep-sea corals and sponge beds that have taken centuries or millennia to grow. The trawlers can target orange roughy, grenadiers or sharks. These fish are usually long-lived and late maturing, and their populations take decades, even centuries to recover.

Fisheries scientist Daniel Pauly and economist Ussif Rashid Sumaila have examined subsidies paid to bottom trawl fleets around the world. They found that \$152 million US per year are paid to deep-sea fisheries. Without these subsidies, global deep-sea fisheries would operate at a loss of \$50 million a year. A great deal of the subsidies paid to deep-sea trawlers is to subsidize the large amount of fuel required to travel beyond the 200 mile limit and drag weighted nets.

- "There is surely a better way for governments to spend money than by paying subsidies to a fleet that burns 1.1 billion litres of fuel annually to maintain paltry catches of old growth fish from highly vulnerable stocks, while destroying their habitat in the process" – Pauly.

- "Eliminating global subsidies would render these fleets economically unviable and would relieve tremendous pressure on over-fishing and vulnerable deep-sea ecosystems" – Sumaila.

Consumer awareness

Sustainable seafood is a movement that has gained momentum as more people become aware about overfishing and environmentally destructive fishing methods. Sustainable seafood is seafood from either fished or farmed sources that can maintain or increase production in the future without jeopardizing the ecosystems from which it was acquired. In general, slow-growing fish that reproduce late in life, such as orange roughy, are vulnerable to overfishing. Seafood species that grow quickly and breed young, such as anchovies and sardines, are much more resistant to overfishing. Several organizations, including the Marine Stewardship Council (MSC), and Friend of the Sea, certify seafood fisheries as sustainable.

The Marine Stewardship Council (MSC) has developed an environmental standard for sustainable and well-managed fisheries. Environmentally responsible fisheries management and practices are rewarded with the use of its blue product ecolabel. Consumers concerned about overfishing and its consequences are increasingly able to choose seafood products which have been independently assessed against the MSC's environmental standard and labelled. This enables consumers to play a part in reversing the decline of fish stocks. As of April 2010, 69 fisheries around the world have been independently assessed and certified as meeting the MSC standard. Their where to buy page lists the currently available certified seafood - as of April 2010 nearly 4,000 MSC-labelled products are available in over 60 countries around the world. Fish & Kids is an MSC project to teach schoolchildren about marine environmental issues, including overfishing.

The Monterey Bay Aquarium's Seafood Watch Program, although not an official certifying body like the MSC, also provides guidance on the sustainability of certain fish species: Some seafood restaurants have begun to offer more sustainable seafood options. The Seafood Choices Alliance is an organization whose members include chefs that serve sustainable seafood at their establishments. In the US, the Sustainable Fisheries Act defines sustainable practices through national standards. Although there is no official certifying body like the MSC, the National Oceanic and Atmospheric Administration has created FishWatch to help guide concerned consumers to sustainable seafood choices.

Fish farming

In 2009, researchers in Australia managed for the first time to coax southern bluefin tuna to breed in landlocked tanks, opening up the possibility of using fish farming as a way to save the species from the problems of overfishing in the wild.

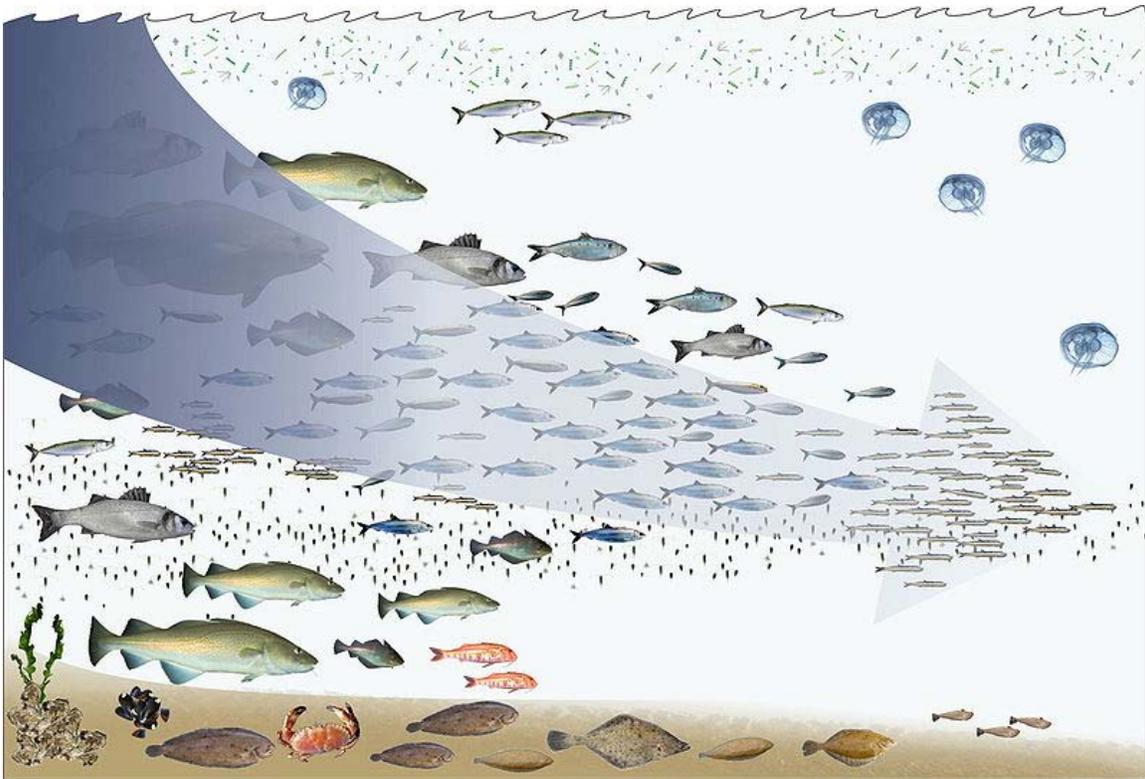
Addendum

Daniel Pauly, a fisheries scientist well-known for pioneering work on the human impacts on global fisheries, comments:

"It is almost as though we use our military to fight the animals in the ocean. We are gradually winning this war to exterminate them. And to see this destruction happen, for nothing really – for no reason – that is a bit frustrating. Strangely enough, these effects are all reversible, all the animals that have disappeared would reappear, all the animals that were small would grow, all the relationships that you can't see any more would re-establish themselves, and the system would re-emerge. So that's one thing to be optimistic about. The oceans, much more so than the land, are reversible..."

Chapter- 7

Environmental Effects of Fishing



Fishing down the foodweb.

The **environmental effects of fishing** can be divided into issues that involve the availability of fish to be caught, such as overfishing, sustainable fisheries, and fisheries management; and issues that involve the impact of fishing on the environment, such as by-catch.

These conservation issues are part of marine conservation, and are addressed in fisheries science programs. There is a growing gap between how many fish are available to be caught and humanity's desire to catch them, a problem that gets worse as the world population grows.

Similar to other environmental issues, there can be conflict between the fishermen who depend on fishing for their livelihoods and fishery scientists who realise that if future fish populations are to be sustainable then some fisheries must reduce or even close.

The journal *Science* published a four-year study in November 2006, which predicted that, at prevailing trends, the world would run out of wild-caught seafood in 2048. The scientists stated that the decline was a result of overfishing, pollution and other environmental factors that were reducing the population of fisheries at the same time as their ecosystems were being degraded. Yet again the analysis has met criticism as being fundamentally flawed, and many fishery management officials, industry representatives and scientists challenge the findings, although the debate continues. Many countries, such as Tonga, the United States, Australia and New Zealand, and international management bodies have taken steps to appropriately manage marine resources.

Effects on habitat

Some fishing techniques also may cause habitat destruction. Dynamite fishing and cyanide fishing, which are illegal in many places, harm surrounding habitat. Bottom trawling, the practice of pulling a fishing net along the sea bottom behind trawlers, removes around 5 to 25% of an area's seabed life on a single run. A 2005 report of the UN Millennium Project, commissioned by UN Secretary-General Kofi Annan, recommended the elimination of bottom trawling on the high seas by 2006 to protect seamounts and other ecologically sensitive habitats.

In mid October 2006, U.S. President Bush joined other world leaders calling for a moratorium on deep-sea trawling, a practice shown to often have harmful effects on sea habitat and, hence, on fish populations.

Overfishing

Overfishing has also been widely reported due to increases in the volume of fishing hauls to feed a quickly growing number of consumers. This has led to the breakdown of some sea ecosystems and several fishing industries whose catch has been greatly diminished. The extinction of many species has also been reported. According to an FAO estimate, over 70% of the world's fish species are either fully exploited or depleted. According to Nitin Desai, Secretary General of the 2002 World Summit on Sustainable Development, "Overfishing cannot continue, the depletion of fisheries poses a major threat to the food supply of millions of people."

The cover story of the May 15, 2003 issue of the science journal *Nature* – with Dr. Ransom A. Myers, an internationally prominent fisheries biologist (Dalhousie University, Halifax, Canada) as the lead author – was devoted to a summary of the scientific information. The story asserted that, as compared with 1950 levels, only a remnant (in some instances, as little as 10%) of all large ocean-fish stocks are left in the seas. These large ocean fish are the species at the top of the food chains (e.g., tuna, cod, among others).

Ecological disruption

Fishing may disrupt food webs by targeting specific, in-demand species. There might be too much fishing of prey species such as sardines and anchovies, thus reducing the food supply for the predators. It may also cause the increase of prey species when the target fishes are predator species such as salmon and tuna. Fisheries can reduce fish stocks that cetaceans rely on for food.

By-catch

By-catch is the portion of the catch that is not the target species. These are either kept to be sold or discarded. In some instances the discarded portion is known as discards.

Possible remedies

Many governments and intergovernmental bodies have implemented fisheries management policies designed to curb the environmental impact of fishing. Fishing conservation aims to control the human activities that may completely decrease a fish stock or washout an entire aquatic environment. These laws include the quotas on the total catch of particular species in a fishery, effort quotas (e.g., number of days at sea), the limits on the number of vessels allowed in specific areas, and the imposition of seasonal restrictions on fishing.

In 2008 a large scale study of fisheries that used individual transferable quotas and ones that didn't provided strong evidence that individual transferable quotas can help to prevent collapses and restore fisheries that appear to be in decline.

Fish farming has been proposed as a more sustainable alternative to traditional capture of wild fish. However, fish farming has been found to have negative impacts on nearby wild fish. Further, farming of predatory fish like salmon can rely on fish feed that is based on fish meal and oil from wild fish.

The environmental impact of recreational fishing may be alleviated to some extent by catch and release fishing.

Chapter- 8

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.

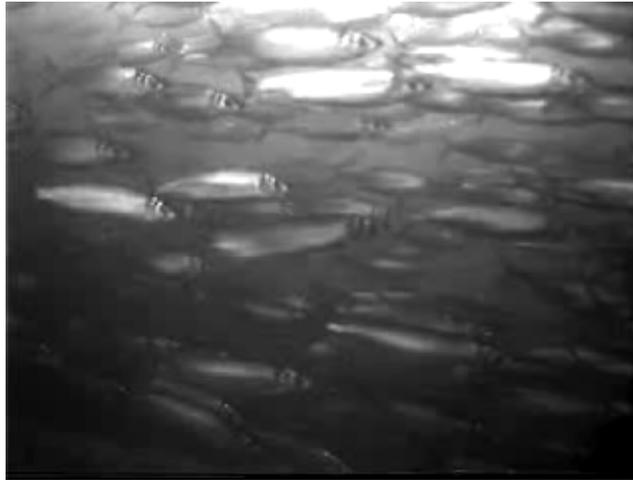
In biology, any group of fish that stay together for social reasons are said to be **shoaling**, and if, in addition, the group is swimming in the same direction in a coordinated manner, they are said to be **schooling**. In common usage, the terms are sometimes used rather loosely. About one quarter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



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 remain close to the other fish in the group. Shoaling groups can include fish of disparate sizes and can include mixed-species subgroups.

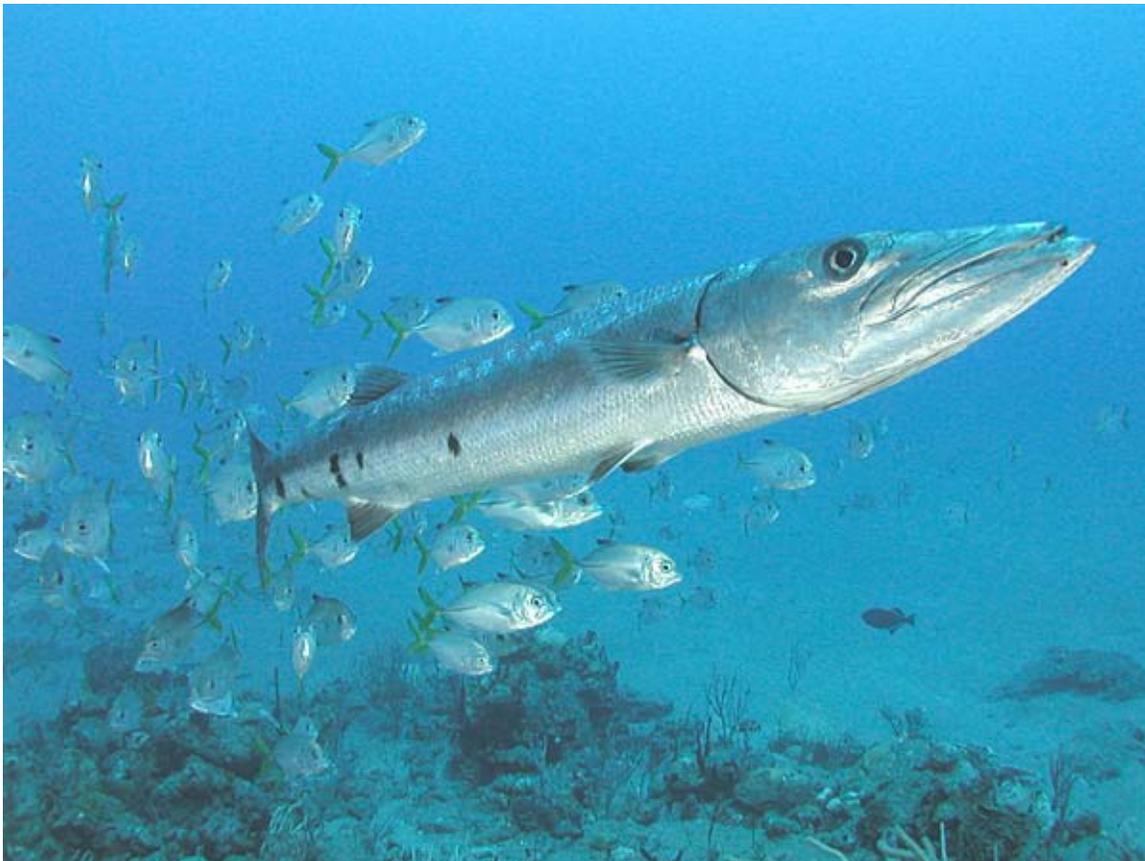
If, as a further addition, the shoal becomes more tightly organised, with the fish synchronising their swimming so they all move at the same speed and in the same direction, then the fish are said to be **schooling**. Schooling fish are usually of the same species and the same age/size. Fish schools 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

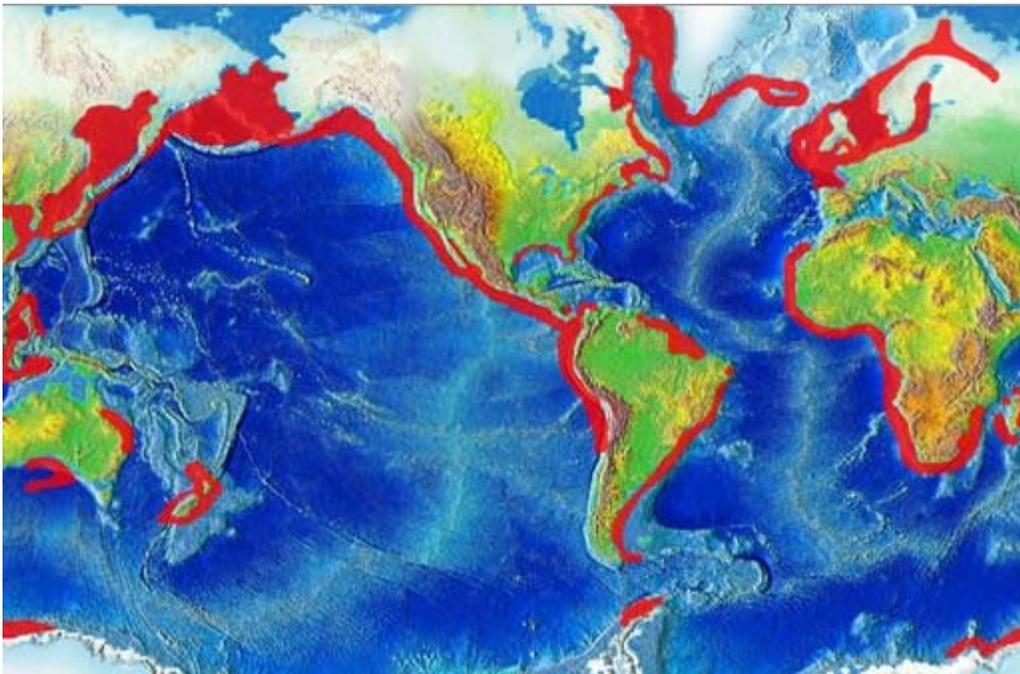
Support for the social and genetic function of aggregations, especially those formed by fish, can be seen in several aspects of their behaviour. For instance, experiments have shown that individual fish removed from a school will have a higher respiratory rate than those found in the school. This effect 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."

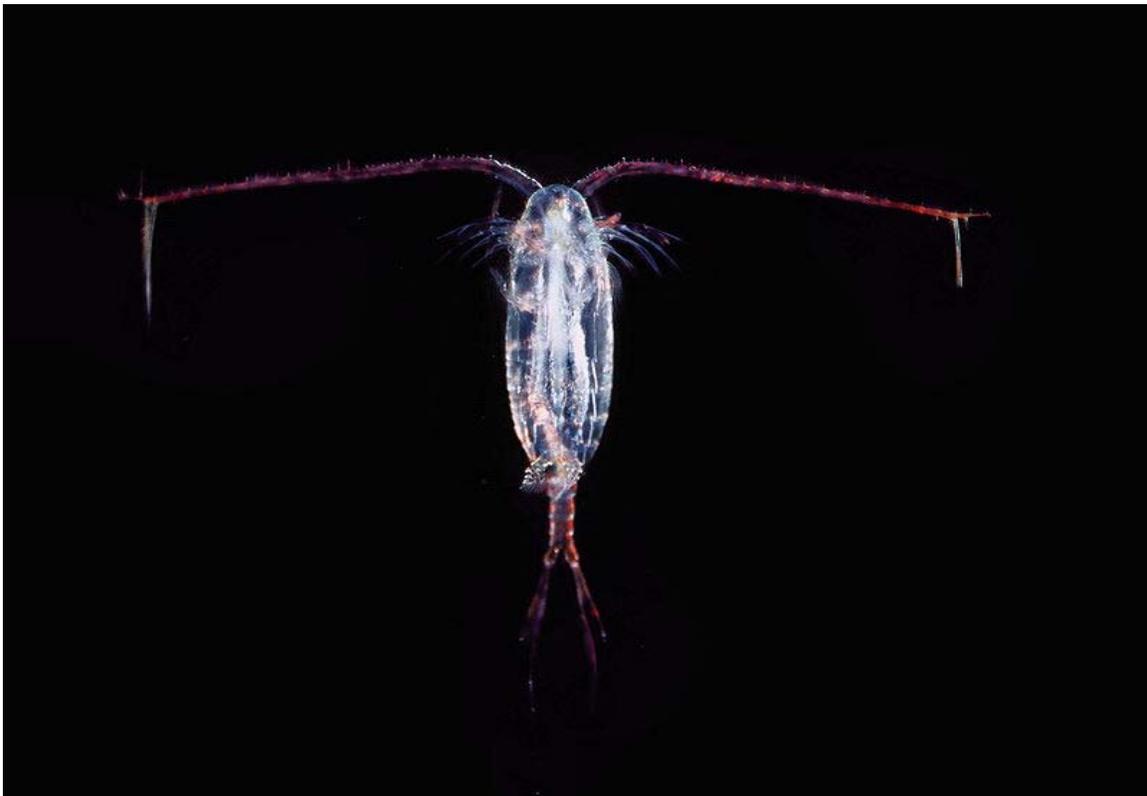


Some coastal upwellings (red) provide plankton rich feeding grounds for shoals of forage fish, which in turn attract larger predator fish.

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. 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

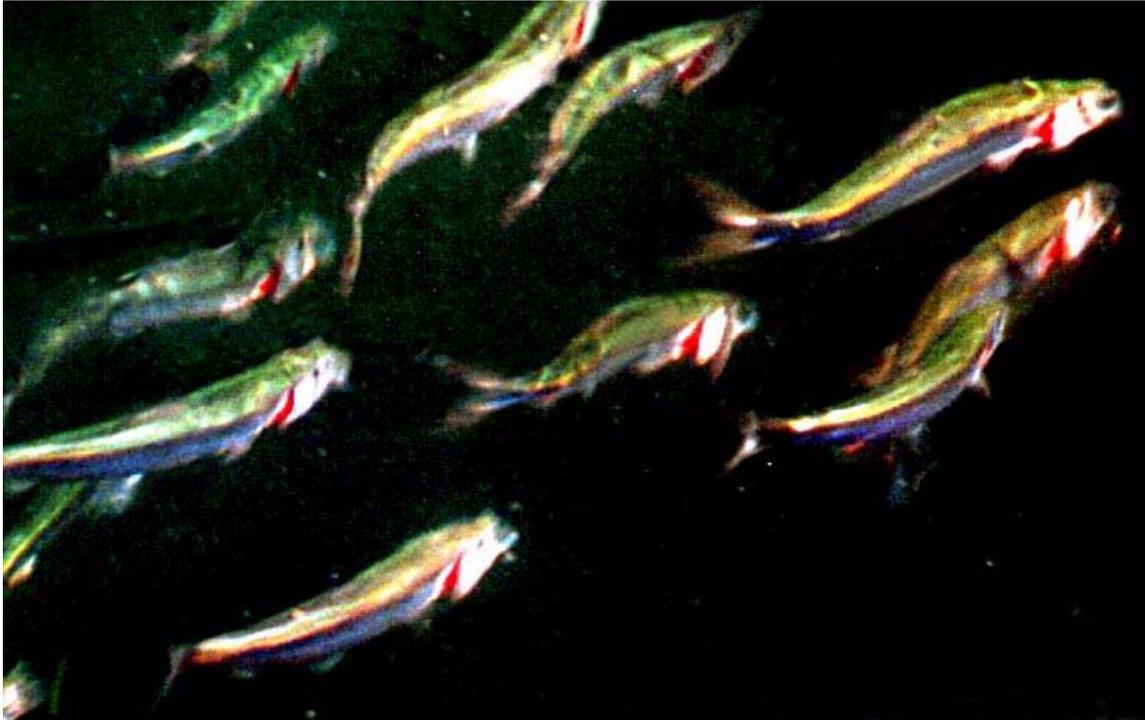


Photo: School of herrings ram feeding on a school of copepods.

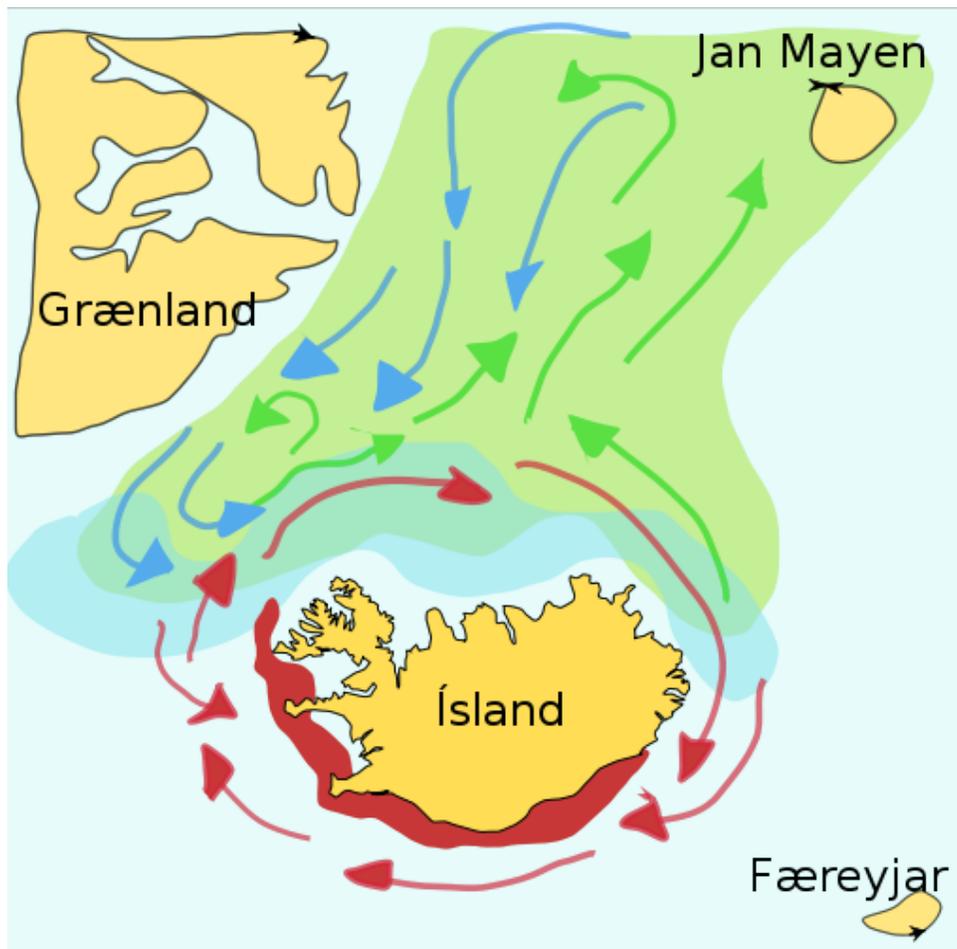


Animation showing how herrings hunting in a synchronised way can capture the very alert and evasive coeppod.

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 animation above right. In the animation, 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 Milinski 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.") Corraling 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.

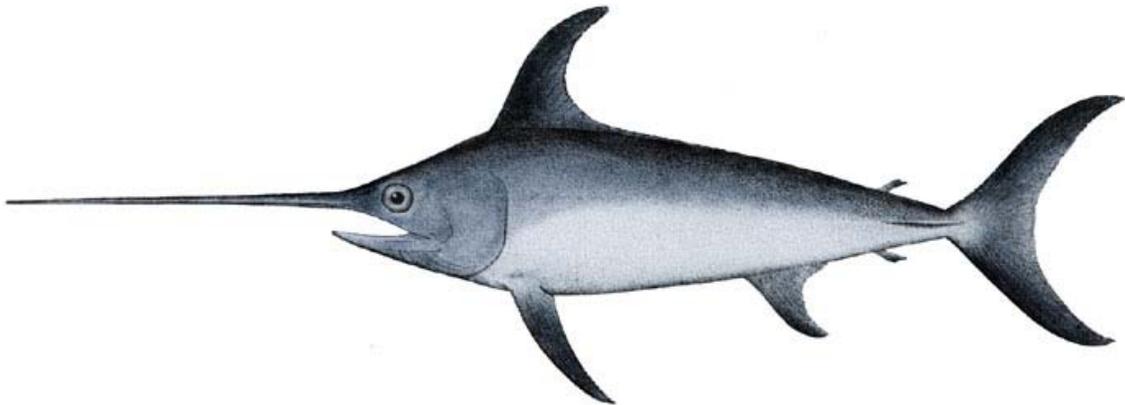
During the sardine run, as many as 18,000 dolphins, behaving like sheepdogs, herd the sardines into bait balls, or corral them in shallow water. Once rounded up, the dolphins and other predators take turns ploughing through the bait balls, gorging on the fish as they sweep through. Seabirds also attack 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.

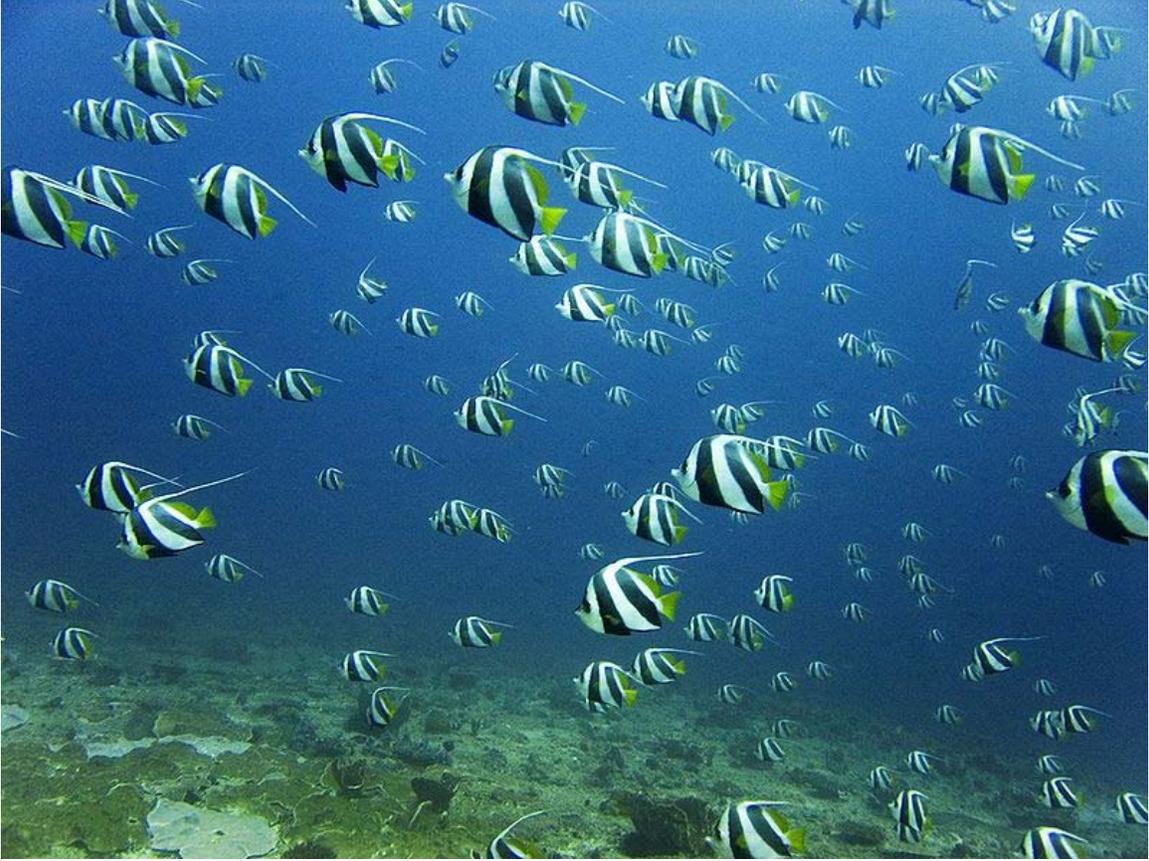
Other senses are also used. The lateral line is a line running along each side of the fish from the gill covers to the base of the tail. In laboratory experiments the lateral lines of schooling fish have been removed. They swam closer, leading to a theory that the lateral lines provide additional stimuli 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.



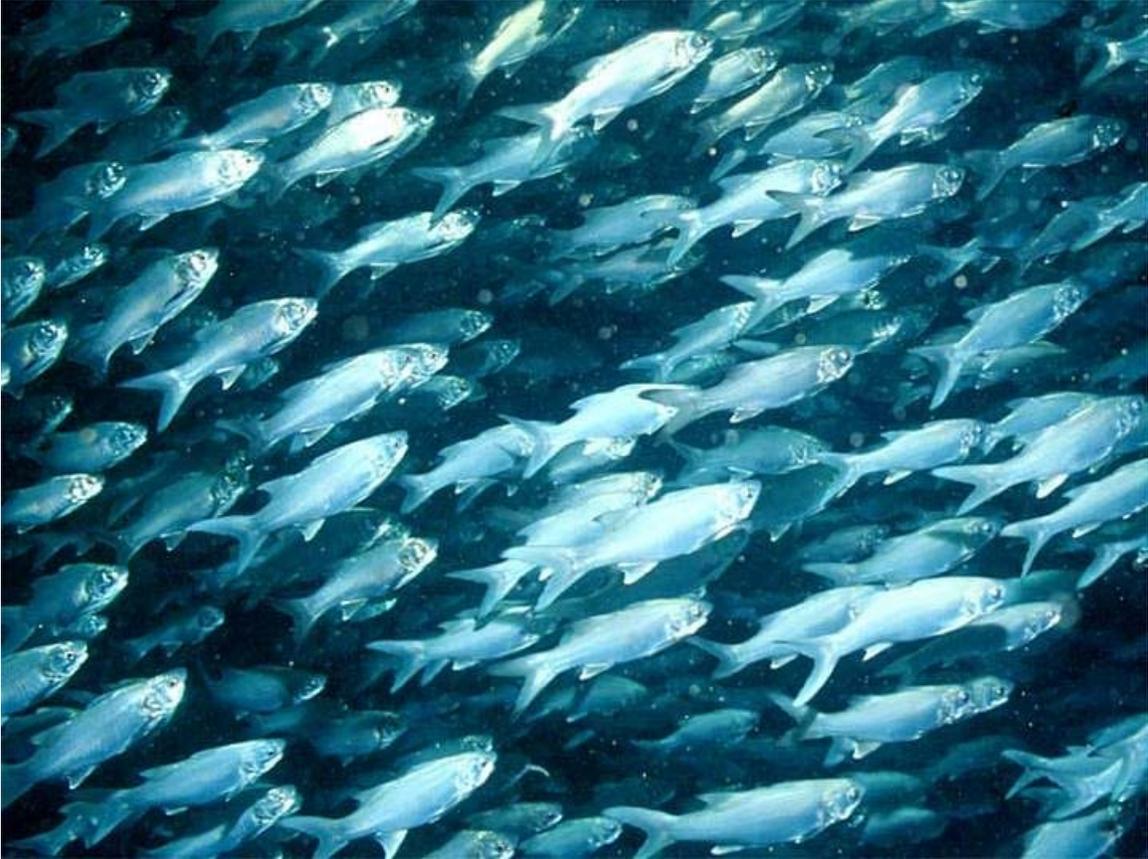
Low density



High density



Low polarity



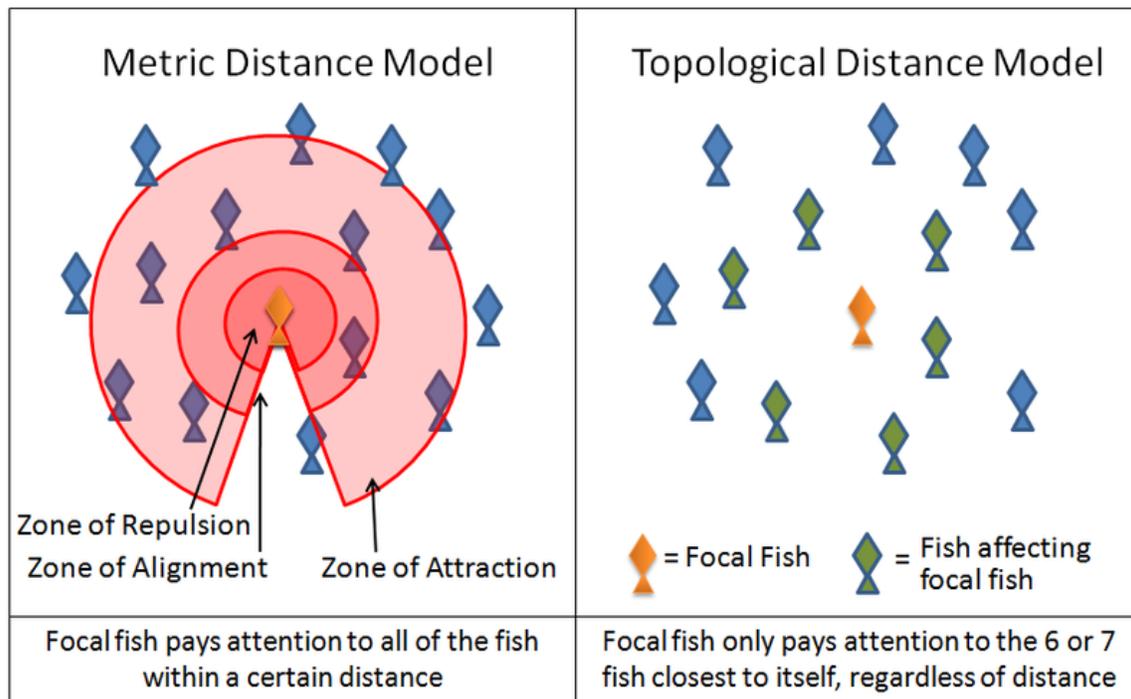
High polarity

- 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).



Passer Angelfish (*Holocanthus passer*)



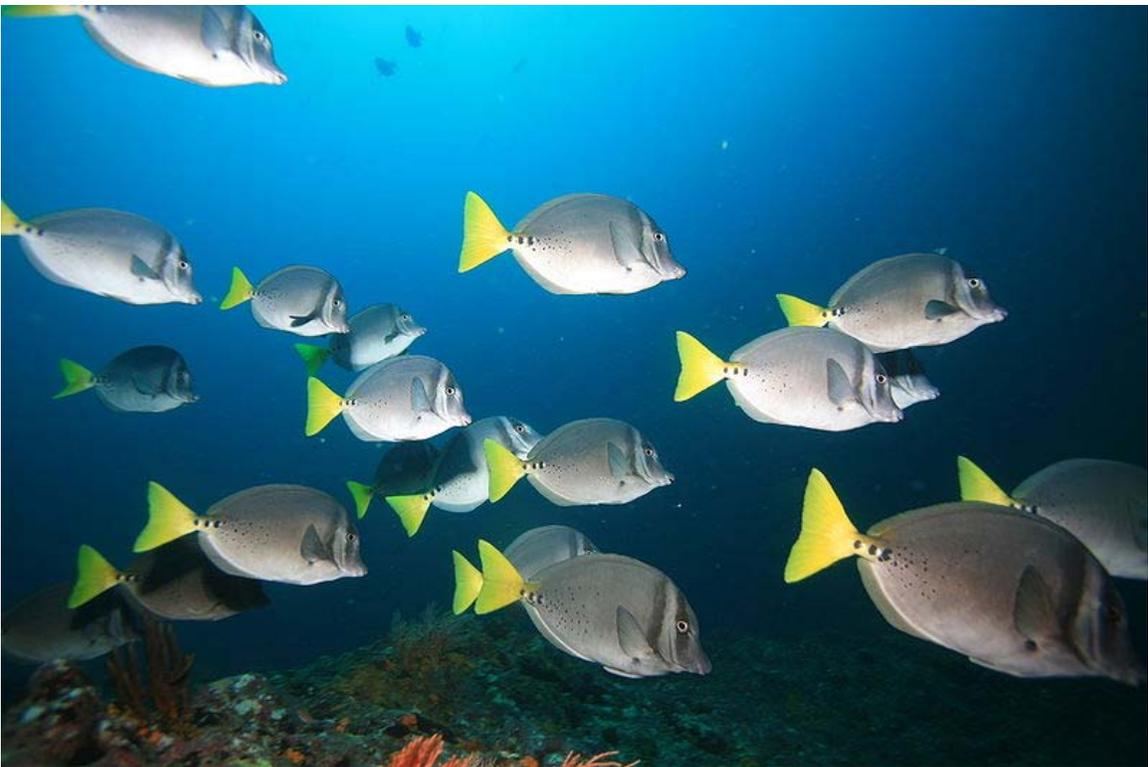
Shool of Silver moony at Madagascar



A school of bar jacks in open water



A school of Golden Crevalle (*Gnathanodon speciosus*)



A school of Yellowtail Surgeonfish (*Prionurus laticlavus*)



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 seniorita fish. When they encounter a shoal of seniorita fish, they stop and form a tight ball and hang upside down (pictured), each fish waiting its turn to be cleaned. The seniorita fish pick dead tissues and external parasites, like parasitic copepods 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.