Phylum Chordata: Vertebrates
The Fish Classes
Introduction

eg. lampreys, hagfish, salmon, trout, sharks, rays, tuna, sardines, flounder, seahorses, catfish, etc etc

oldest known vertebrates
  → 530 MY (early Cambrian) fossils

all fish are aquatic & and highly adapted for aquatic life: freshwater and saltwater habitats

there are no terrestrial fish; although some can survive considerable time outside of water and can often be found crawling on land

  eg. walking catfish

fish are the most diverse and successful group of living vertebrates

  → almost half of all vertebrate species
  → 21,000 living species

  → ~100 new species described each year

smallest fish = pygmy gobi <1/2"; smallest living vertebrate

largest fish = whale shark to ~50’, rumors to 70’ (40 tonnes)

most fish continue to grow throughout adult life

(birds & mammals stop growing at adulthood)
**Skin**

most with slimy skin and/or *scales* embedded in skin

the slimy skin reduces friction to improve swimming efficiency (along with overall shape of fish)

**Skeleton**

highly flexible “backbone” of cartilage or bone is main support and framework for swimming muscles

most fish have *ribs* on which swimming muscle are attached

also, most fish have *paired appendages*  
&lt;appendicular skeleton

paired fins: pectoral and pelvic  
→ homologous to our arms and legs

act as rudders, for balance, feelers, weapons, sucking discs, lures to attract prey

**Movement**

mainly swimming

although some can walk, crawl, burrow, and “fly”

less energy is required for swimming than most
other forms of locomotion

→ water is 800x’s denser than air
don’t need to also fight gravity as much

most of a fish’s body mass is bundles of muscle tissue for swimming = \textbf{myomeres} (=\textbf{myotomes})

relatively small body cavity for other organs

muscles are segmented
→ zig-zag “W”-shaped bands of muscles along sides of fish

each myotome consist of short muscle fibers connected to tough connective tissue that are also attached to the next myotome

each myotome extends across several vertebrae
→ allows more power and fine control

produce “S” shaped swimming motion

fish actually “push” on the water

water is relatively dense
non compressible

fish get most propulsion from hind trunk & tail muscles

\textbf{dorsal and ventral fins} improve swimming efficiency
Respiration

Gills for getting O$_2$ from water

- efficient respiration in water
  - thin feathery sheets with lots of blood vessels
- some scaleless fish can also breath through their skin

Circulation

blood is pumped through arteries and veins with simple heart

- most with 2 chambered heart;

  - single circuit:
    - heart $\rightarrow$ arteries $\rightarrow$ capillaries $\rightarrow$ veins

  - blood is first pumped through gills then out to the rest of the body (ie. single “circuit”)

Nervous System & Senses

- brains are relatively small and simple but still considerably more developed than in the invertebrates
Animals: Chordates - Fishes; Ziser Lecture Notes, 2006

**sense organs**

**eyes**

paired eyes

in most fish they are set (at rest) for near vision

in sharks (as well as amphibians and snakes and humans) eyes are relaxed for far vision

also, unlike our eyes that stretch lens to change focus; muscles in fish eyes move lens forward or backwards to focus

**lateral line system** = "distance touch"

interconnected tubes and pores along sides of body

detects vibrations and current

**chemoreceptors**

nose
Kinds of Fish:

28,078 species

three different classes of vertebrates are categorized as “fish”:

1. jawless fish (Agnatha)
   108 species

2. cartilaginous fish (Chondrichthyes)
   970 species

3. bony fish (Osteichthytes)
   27,000 species (96% of all fish)
   most abundant living group
   2 main types: ray finned fish
                   lobe finned fish
The Agnatha
(Jawless Fish)

(108 living sp)

only living vertebrate group with no jaws

oldest known vertebrates

most ancient & primitive vertebrate group

→ over 500 MY fossils of jawless fish

fossil agnathans are found >500 MY
include extinct conodonts & ostracoderms

three main groups of agnatha:

  ostracoderms - all extinct
  hagfish
  lampreys

Ostracoderms

circular or slit-like mouth opening without jaws

some of the earliest vertebrate fossils are in this group
(late Cambrian to Ordovician)

recently Chinese fossils pushed date back to 530 MY

flourished for 150 MY
became extinct at end of Devonian

fish armored with heavy dermal bony plates

no paired fins

probably stayed close to bottom

may have filtered water for food but not with cilia & mucus as in cephalochordates

used pumping action of muscular pharynx

some may have even been predators

a later group of ostracoderms had paired **pectoral fins**

→ greatly improved swimming ability

also seemed to have a more sophisticated nervous system and sense organs

→ similar to today’s lampreys

probably filtered particles from water

but instead of cilia and mucus, they used muscular pumping of pharynx to take in food

a later group of ostracoderms were even more streamlined (=anapsids)
General Characteristics of living Agnatha:

1. can be freshwater or marine
2. long eel-like body form
3. no jaws
4. no paired fins
   generally poor swimmers
5. smooth slimy skin, no scales
6. skeleton is a simple rod of cartilage, no bone
7. gills located inside 5-16 pairs of pore-like gill openings
   spiracle at top of head can draw water in and over gills
8. poor sense organs
9. parasitic or scavengers

two main forms today:
   hagfish
   lampreys
Hagfish

70 species
all are marine
found in deep waters
→ almost completely blind; eyes have degenerated

Feeding & Digestion

scavengers, predators & omnivores
→ eat dead or dying fish, molluscs, annelids, etc
although almost blind they can quickly find food by touch and smell
enters dead or dying animal through an orifice or by actually digging into the animal
has 2 toothed keratinized plates on its tongue
rasps bits of flesh from carcass

Circulation

has unusually low pressure circulatory system
with 1 main heart and 3 accessory hearts to boost blood pressure through gills
Excretion

only vertebrate with body fluids the same concentration as salt water (invertebrate trait)

Protection

secrete copious amounts of slime (500 ml/min)

→ milky fluid from slime sacs along sides of body

→ on contact with seawater forms a very slippery material making them impossible to hold

→ protection from predators

Reproduction

breeding habits are still relatively unknown

animal has both male and female gonads but only one or other is functional

no larval stage

Human Impacts

bane to some commercial fishermen using gill or set nets

→ by the time they pull catch in hagfish have
often devoured internal contents of fish
not often a pest with trawl fishing
today hagfish are collected for “leather” to make golf bags and boots
some species are in serious decline due to over harvesting

**Conodonts**

numerous fossils of small toothlike structures have been known for years
common → used as index fossils to date sediments
weren’t sure what animal produced them until 1980 when fossils of complete animal were found

was an agnathan, apparently most closely related to hagfish

had toothlike plates in throat area

notochord

swimming muscles as myomeres

paired eyes

similar inner ear structure
Lampeys

38 sp.; 20 sp in North America
most 15 - 60 cm; up to 1 M long

**Feeding & Digestion**

most are parasitic

others don’t feed as adults

parasitic adults attach to prey by sucker like mouth

rasp away flesh with teeth to suck out blood

→ inject **anticoagulant**

when finished lamprey releases its hold

host sometimes dies from wound

**Reproduction**

all spawn in winter or spring

→ in shallow freshwater streams

male builds nest

→ uses oral disc to move stones and make a shallow depression
female joins him

female attaches to rock to hold position in current

male attaches to female and fertilizes eggs as they are released

adults die after spawning

eggs are sticky, covered with sand

in 2 weeks eggs hatch into ammocetes larvae

→ close resemblance to amphioxus

larvae drift downstream and burrow into sand

larvae are suspension feeders for 3-7 years

feeding on microscopic organisms

then rapidly metamorphose into adults:

larger eyes
oral disc with rasping teeth
nostrils shift to top of head
body shorter and rounder

all lampreys migrate up freshwater streams to breed

eggs and larvae develop in freshwater

→ young of marine species then migrate to ocean
until sexually mature

→ others remain in freshwaters their entire lives

**Human Impacts**

*Petromyzon* first invaded the great lakes in 1913-1918 (bioinvasion)

in 1950’s destroyed great lakes fisheries

rainbow trout, whitefish, lake herring, and other species populations were destroyed

their numbers began to decline in early 1960’s

due to depleated food

expensive control measures

→ expensive larvacides placed in selected spawning streams

today, some native species have been restocked and are now thriving again
Jawed Fish

Origin of Jaws & Paired Fins

Evolution of **jaws** was one of the major events in the history of vertebrates

→ freed from bottom feeding

→ could become predators

Oldest known jawed vertebrates appeared 420 MY (Silurian)

→ **placoderms** and **acanthodians**

**Jaws** evolved from gill supports (gill arches)

→ in certain primitive fish the jaws resemble gill arches

→ in shark embryology jaws do develop from gill arches; can watch it happen

→ cranial nerve branching and placement in jaws and gills of cartilaginous fish resembles each other

Initially, jaws just “closed the mouth”

Jaws allowed feeding on larger foods:

- plants and animals

Later jaws became armed with scales that evolved into **teeth**
teeth could be used to seize prey

jaws allowed predation on larger active prey

acanthodians and placoderms were also 1st fish with paired fins

all living jawed fish (gnathostomes) also have paired pectoral and pelvic fins

pectoral fins appeared before pelvic fins

probably originated as stabilizers for swimming

might have begun as folds in skin along sides of animal

later got muscle attachments and became moveable

Placoderms

heavily armored fish with jaws

some up to 10 M long; very diverse group

Acanthodians

live on today as bony fish

acanthodians had scales rather than bony plates of placoderms

once jaws & fins evolved there was an explosion in fish
diversity

→ Devonian = “age of fishes”

Placoderms and acanthodians went extinct at end of Devonian
Class Chondrichthyes  
(Sharks and Rays)

970 species  
ancient group  
  all but a few are marine  
includes the largest fish and second largest of all living vertebrates  
  whale shark → up to 12 M long  

**General Characteristics of Sharks**

1. mostly predators  
2. endoskeleton of cartilage  
3. powerful jaws  
4. very efficient muscles and shape for swimming  
5. well developed sense organs  

**Body Form**

fusiform (spindle shaped)

**Skin & Scales**
skin is very tough & leathery

→ muscles of shark pull on skin rather than pulling on the skeleton

hard, knife-like (placoid) dermal scales are embedded in skin and stick out from skin

made of bony tissue

scales have same structure as tooth including enamel, dentin & pulp cavity

scales are continuously shed and replaced throughout life

Support

skeleton lost bone of ancestors and became completely cartilaginous

sharks evolved from fish with bone - neoteny??

but retained mineralization in teeth, scales & spine

paired appendages: pectoral and pelvic fins

pectoral fins are rigid, not flexible

powerful dorsal and caudal fins

Muscles & Movement
most of body is muscle mass (myotomes) is for swimming

sharks have excellent swimming ability

sharks are the most graceful and streamlined of all fish

sharks are among some of the fastest fish:

eg mako shark 60mph
eg. blue shark 43 mph

Buoyancy

large liver is rich in fats and oils giving sharks near neutral buoyancy

→ don’t need to use energy to maintain position in the water column

Feeding & Digestion

most sharks are predators

yet, by nature, most tend to be timid & cautious

powerful jaws

jaws are suspended from chondrocranium by ligaments
→ free movement

teeth only grasp prey, don’t chew
the teeth and (dermal) scales of sharks are essentially the same enamel covered dentin same structure and composition both shed regularly

teeth are enlarged scales

form replaceable rows of teeth eg. fossil shark teeth

skates and rays have broad, blunt, cobblestone-like teeth for crushing clams, oyster, etc

some sharks are plankton feeders:

eg. whale shark (>50’); worlds largest fish
eg. basking shark (15-40’)

a few are scavengers

digestive system is similar to other vertebrates but with spiral valve to slow food and increase area of absorption

Respiration

gills used for respiration

rows of separate gill slits similar to agnatha

spiracles can take in water when mouth is occupied
sharks must be moving or there must be some current to move water over the gills

Circulation

similar to lampreys

two chambered heart with single circuit going to gills then rest of body and back to heart

Brain & Sense Organs

small brain but well developed sense organs to locate prey

Senses

a. lateral line system

detects vibrations and current

b. chemoreceptors esp in olfactory pits on head open through nostrils

widely spaced nostrils allow shark to more easily localize prey

    can detect prey half mile or more distant

c. eyes not particularly good but used at close
range

d. **ampullary organs (of Lorenzini)**

electroreceptors in head

senses bioelectric fields around animals

used especially for final stage of attack

**Excretion**

have 2 long slender **kidneys** for excretion

**gills** also play role in excretion and osmoregulation

→ secrete NH$_3$ and other N wastes

retain urea to help maintain internal fluids isosmotic to sea water

also, **rectal gland** assists kidney

secretes excess salts

**Reproduction & Development**

dioecious

all sharks have internal fertilization
male sharks & rays with **claspers** on pelvic fins

→ used to transfer sperm (NOT for clasping)

usually produce only a few eggs at a time

some skates produce 2 young each time

no member of the group produces >12 at a time

retain eggs in body till hatch

development lasts 6 months to 2 years

some sharks have primitive uterus and placenta
and provide “uterine milk” for developing young

→ bear live young! (viviparous)

others get extra nutrition by eating eggs and siblings in uterus

some sharks and skates have internal fertilization but deposit eggs in horny capsule

= **mermaid’s purse**

each “purse” may contain several eggs

often has “tendrils” to attach to objects

no parental care after eggs are laid or young are born
eg. **Skates and Rays**

~ half of all chondrichthyes

mainly bottom dwellers

dorsoventrally flattened

enlarged *pectoral fins* = ‘wings’

move in wavelike fashion

gills open on underside but have large *spiracle* on top to take in water

in sting rays caudal and dorsal fins have been lost

tail is slender and whiplike

armed with 1 or more *spines*

teeth adapted for crushing prey
  (molluscs, crustaceans, small fish)

dioecious
  many bear live young

eg. **Electric Rays**

fish are the only animals that can directly produce an electrical shock
the ability to produce electric shocks is confined to only 2 groups of vertebrates:

→ electric rays and some bony fish

electric rays are generally slow, sluggish fish that live in shallow waters

have some muscles modified into electric organs to shock prey or stun predators

  cells connected parallel
  → high amperage, low voltage

  → high power output – up to several kilowatts

electric rays were used by ancient Egyptians as “electrotherapy” treatment for arthritis and gout

**eg. torpedo ray:**

contains 400 honeycomb-like prisms filled with clear jelly-like mass

nerves connect organ to lobe of brain = electric lobe

each cell generates .02-.05 volts
  → can generate combined shock of ≤35 Volts

the amount of electricity varies greatly

can only give a few shocks before it has to rest and eat
Ecology

top predators in many ocean food chains
Human Impacts

1. Shark attacks

60 - 70 per year \(^{(2000-2006)}\); 1-10 fatalities

especially great white (to 6 M long)
mako
tiger
bull
hammerhead

more casualities reported from Australian region than anywhere else

2. Shark fishing

40 Million/yr are harvested

100,000 killed for “shark fin soup”

sells for up to $100/bowl

“finning” has been outlawed in US

some other countries are setting quotas

3. Medicinal/Pharmaceuticals

electric rays were used by ancient Egyptians as “electrotherapy”
treatment for arthritis and gout

chondroitin for joint treatment and health
extracts are being tested for anticancer drugs and weight loss
Class Osteichthyes
Bony Fish

27,000 sp; (96% of all fish)

~200 new species are described each year

probably 5-10,000 more undescribed species

most successful vertebrate class

7 mm to 17 M (oarfish) & 4.5 M blue marlin

have adapted to every kind of aquatic habitat

from 8000 M deep to 5200 M in Tibet

some in hot springs (44º C)

others under anarctic ice at -2º C

in totally dark caves

some make excursions onto land

most bony fish are designed for active swimming

but great diversity of size & shape due to differences in lifestyles

→ adaptive radiation

amazing diversity of body form:

eg. streamlined bodies to reduce friction
eg. trim, elongated bodies of pelagic predaceous fish with powerful tails → predators

eg. flattened bodies in bottom forms

eg. eellike - wriggling into holes and crevices

eg. grotesque forms cryptic or mimic for protection

actually consists of several distinct groups which probably should be considered separate classes

**Skin & Scales**

body is covered with mucous secreting **epidermis**

**slime** is used to reduce friction

→ can reduce it up to 66%

most have thin, overlapping dermal **scales** below epidermis

replaced heavy bony dermal scales of sharks

several types of scales:

eg ganoid → bony, don’t overlap

others do overlap

some have completely lost scales

unlike sharks, bony fish do not shed scales

they grow throughout life
can be used to age fish

color and bioluminescence

skin of bony fish shows a variety of colors and texture

⇒ used for eg. protection, mimicry, warning, camouflage

skin of fish shows a variety of colors and texture

⇒ used for eg. protection, mimicry, warning, camouflage

eg. concealment:

et. coral reef fish are highly colored
but on reef cant see them

et. fw fish shades of green, brown, blue above
and silver or yellow white below

⇒ from below blends with sky,
from above blends with substrate

et. often have blotches, spots and bars
⇒ ~army camouflage

eg. mimicry

another form of camouflage

et. pipefish, anglerfish, sargassum fish

take coloration, texture and form of seaweed
eg. warning:

many highly colored fish stand out from their surroundings

→ warn potential predators that they are poisonous

most fish can control their color to some degree
due to special skin cells = **chromatophores**

controlled by nervous system

in dermis

can be: silver, yellow, orange, black

blended for other colors

allows fish to change color to blend with substrate

color changing is most highly developed in flounder (flatfish) species

**bioluminescence**

the skin of some fish also contains **photophores**

→ light emitting organs or structures

found in many unrelated groups
may be on head; lateral line, sides of belly, on barbels, etc

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**Support**

cartilaginous skeleton is replaced by bone in adults of most species

a few species retain cartilage skeleton
# of vertebrae on a fish varies from 16 to >400

ribs of fish not used for “breathing”

→ support swimming muscles

**fins** contain bony or cartilage rods

= rays connected by thin membranes

**pectoral** and **pelvic fins** are controlled by muscles for more precise movements

**dorsal fin** is moveable and sometimes becomes highly specialized for:

- camouflage
- venomous spines (eg. scorpion fish)
- lures (eg. anglerfish)

**Movement**

most of body mass is segmented **myotomes**

(2/5ths of body volume in most; 3/4ths in tuna)

movement is mainly swimming,

but some can walk, crawl, burrow, or “fly”
less energy is required for swimming than most other forms of locomotion

→ don’t need to fight gravity

→ “S” shaped swimming motion

get most propulsion from hind trunk & tail muscles

fish actually “push” on the water

water is relatively dense

non compressible

the most rapid fish exchange the snake-like motion for more rigid position where most of the flexing is toward the tail only

eg. tuna doesn’t flex body at all; all thrust is from the tail

overall, swimming speeds not particularly fast compared to running or flight

→ water is 800x’s denser than air

eg. 1 ft trout → 6.5 mph
eg. 2ft salmon → 14mph

the larger the fish the faster it can swim
barracuda is fastest fish $\rightarrow$ 27 mph

usually cruising speed is much slower

most speeds reported for fish are speeds as they jump out of water so they appear to be much faster

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<thead>
<tr>
<th>Maximum Speeds</th>
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<tr>
<td>sailfish</td>
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flying fish can achieve launch speeds of 35mph and glide above the water 20-40 seconds

very flexible and moveable **pectoral** and **pelvic fins**

pectoral fins used to steer and swim

**Buoyancy**

all fish are slightly heavier than water

to keep from sinking, sharks must keep moving

shape of sharks tail provides lift

most bony fish have **swim bladder** to control buoyancy

swim bladder arose from “lung” of some primitive
bony fish

they lived in swamp waters with low O₂ levels
needed accessory oxygen source

(called a lung if used mainly for respiration;
called swimbladder if used to control buoyancy)

most early bony fish evolved and diversified in freshwaters

alternating wet and dry temps made lungs essential in some forms

by adjusting the volume of gas (O₂) in the swim bladder
a fish can achieve neutral buoyancy and remain suspended indefinitely with no muscular exertion

control of buoyancy probably coevolved with fin modifications to improve and refine locomotion

most pelagic fish have swim bladders (except tuna)

bottom fish generally lack swim bladders (eg. flounder)

in fish that migrate to & from great depths have the additional problem of the gasses being forced into blood

eg. humans suffer the bends when returning to surface as gas comes out of solution and forms bubbles in the blood
fish are able to prevent gasses from entering body fluids at great depths and keep body fluids at equilibrium with oxygen in surface waters. Their swim bladders can resist pressures > 240 atm (up to 8000’ depth) (= pressure inside compressed gas cylinders) and still keep oxygen in blood at 0.2 atm (~ sea level pressure).

**Feeding & Digestion**

After the evolution of jaws, fish were freed from deposit feeding and filter feeding. They diversified into a variety of feeding types:

Most fish are **carnivores**.

Most lack tongues.

Also chewing would produce pieces that might clog gills

⇒ must swallow their food whole

**a. Plankton feeders**

Most common feeding type.

Most pelagic species are plankton feeders (zooplankton)

Eg. herring, anchovies, menhaden.
travel in large schools
plankton are strained with sieve like gill rakers

b. predators

teeth used to seize prey
a few have molar-like teeth behind gills to grind food
gill arches of some fish are modified into “pharyngeal jaws” for chewing, grinding & crushing

c. herbivores

eat plants, grasses, algae, etc

d. omnivores

e. scavengers & detritivores

suckers & minnows

f. parasites

intestine long to provide greater surface area
- no spiral valve
**Respiration**

Fish get oxygen mainly through **gills**

- Gills are located inside **pharyngeal cavity**

- Gills are highly vascularized filaments of soft tissues covered with a thin epidermis

- Often have "**gill rakers**" that filter water before passing over gills

  - To remove food and bits of debris that might clog the gills

- Gills are covered bony flap = **operculum**

  - Offers protection and reduces friction when swimming

  - Operculum can also actively pump water across gills

  - Fish can still "breath" even if not moving

**Body Temperature/Thermoregulation**

- Fish are cold-blooded; ie **poikilotherms**

  - The body temperature of most fish is the same as
their environment

some fish eg. tunas, mako sharks, maintain a higher temperature in their swimming muscles

→ as much as 10º C warmer than surrounding water

other fish; eg. marlins, elevate temperature of brains and retinas

elevated temperatures promote swimming and enhance nervous activities

→ such fish are some of the fastest in the world

**Nervous System & Senses**

simple brains as described for Fishes in general

fish do **sleep**

→ stay motionless for several hours

some marine species (eg. wrasses, Labridae) may bury themselves in sand or spin “sleeping bags” → cocoons of mucus each night to sleep

**Senses**

the fishes environment:

light doesn’t travel as far in water
also turbidity

sound and pressure waves travel faster and further

a. eyes

most fish lack eyelids

one eye of flounders migrates to same side as other eye during embryonic development

a few freshwater fish have “bifocal” lenses to see above and below the water at the same time

  can enhance prey perception

fish can see in color

  can also detect polarized light → navigation

b. lateral line system

bony fish also depend mainly on lateral line system for sensory information to detect food or danger

contains:
  mechanoreceptors → water movements
  electroreceptors
  chemoreceptors
can also pick up unusually low frequency sounds (.1-200 Hz)

c. **Chemoreceptors (smell and taste)**

chemicals also travel well in water

for fish there is no clear distinction between smell and taste

chemoreceptors are located in:
  - mouth
  - around head
  - in some over entire body
  - catfish and loaches on barbels around mouth
    (barbels also for touch)

fish lack taste buds

  but can apparently discriminate between bits of food and trash that they take in

    → will expel unwanted items that they eat

**olfactory sacs** (=nose)

  fish don’t “breath” through their nose

    → nostrils are just sensory pits

most fish have a good sense of smell
prey detection

communication (with pheromones)

d. touch

barbells in catfish, goatfish, whiting, etc

e. hearing

swim bladder has secondary function in hearing

swim bladder is connected to inner ear by set of bones = **Weberian ossicles**

sound vibrations are picked up by swim bladder and transferred to ear through ossicles

acts kind of like an eardrum and ear ossicles in humans

helps to amplify even very faint sounds in water

f. balance

otolith organ and semicircular canals

swim bladder is close to inner ear → acts as a receiver and transmitter
transmits vibrations to inner ear

inner ear can pick up frequencies up to 8000 Hz

no outer ear or eardrum

**Water Balance & Excretion**

scales & mucus make body almost completely impermeable to water

→ most gain & loss is through gills

all modern bony fishes are believed to have descended from ancestors that evolved in freshwaters.

→ **marine bony fish** (returned to oceans from freshwater) have salt content about one third that of seawater

→ **freshwater fish** have salt content ~100 times greater than freshwater they live in

[fw salt conc=.001-.005 Moles; freshwater fish = .2-.3 M]

“**Water follows Salt**”

**marine fishes** has a tendency to lose water and

**freshwater fishes** has a tendency to take on water
most of this exchange occurs through the gills and mouth

marine fish urinate little and drink large amounts of seawater while pumping out excess salts from gills

freshwater fishes must avoid drinking and urinate often while getting ions through food and gill uptake

because of these osmotic limitations 90% of all fish are restricted to either freshwaters or salt water

10% of fish are able to easily move between freshwater and salt water = euryhaline fish

→ can actively regulate to maintain salt/water balance in their internal fluids

Defenses

color and shape can be used for camouflage

some fish are highly venomous; eg scorpionfish

Electric Fish

water conducts electricity

the ability to produce electric shocks is confined to only 2 groups of vertebrates: electric rays and some bony fish
bony fish: electric eel & electric catfish

eg. electric eel

in rivers in South America

grows to 3 - 7 ft long

electric organ is modified muscle tissue

→ up to 40% of body weight

most powerful electric organ of all fish

→ can produce 600 volts to stun or kill prey

→ can give several 100 shocks up to 300 V each/second

doesn’t need to actually touch victim

→ electric field extends several feet around fish

eg. electric catfish

found in the Nile river

organ seems to have evolved from the skin rather than from muscle tissue (?)

consists of a uniform layer of gelatinous tissue

Reproduction & Development

most fish are **dioecious**

only a few are hermaphrodites

genders cannot be distinguished externally
most with external fertilization (oviparous)

a few bear live young (eg. guppies)

→ generally little or no parental care

most fish produce large numbers of eggs:

- eg. herring → 25,000
- eg. lumpfish → 155,000 - 1M
- eg. halibut → 3.5 M
- eg. sturgeon → 635,500
- eg. cod → 4 - 6 M

→ less than 1/million will survive to maturity

most fish spawn at certain times of the year

→ spawning is temperature dependent

→ temperature is critical for survival of eggs and young

in most marine fish: eggs are released and become part of the plankton through embryonic and larval development

some fw fish make nests and have fairly elaborate mating and nesting behaviors

eg. Stickleback

male constructs very elaborate nest of grass and weeds bound by mucous threads

(only example of “case building” in a vertebrate animal)

then looks for a mate to entice inside

if gentle persuasion doesn’t work, he may drive 1 or 2
females into nest until enough eggs are laid then he jealously guards them for many days until they hatch

**eg. Tilapia**
starting in late spring they begin to spawn males build circular nests in streambed females choose mate based on nest both spawn over nest after eggs hatch mother will carry the young in her mouth for a few weeks then they are on their own

A few fish show rather elaborate parental care

**eg. some Catfish species**
females attach eggs to underside and she carries them around till they hatch

**eg. pipefish & seahorses**
males contain a brood pouch female lays fertilized eggs in males pouch they remain there for ~ 10 days till hatching

**eg. some marine catfish**
eggs are incubated in males mouth young continue to be carried and protected in males mouth after they hatch male doesn’t eat for ≥ 1 month

some fish show absolutely no parental care or interest

**eg. Gambusia**
in an aquarium will eat all their young as soon as they are born

fish continue to **grow throughout life**

**generally growth is temperature dependent**
**Annual rings** are produced in scales, otoliths and other bony parts

→ the age can be accurately determined

### Migrations

Some fish spend most of their lives in freshwater but return to sea to spawn

= **catadromous** (“down running”)

Eg. Some eels

Each fall large numbers of female eels are seen swimming down rivers toward the sea.

When adults leave rivers in Europe and N America they reach ocean and swim at great depths to Sargasso Sea.

Takes several months to reach this area; here they spawn and die.

They tiny larvae begin their return trips to the coastal rivers → takes up to 3 yrs in Europe.

Each spring large numbers of young eels appear in coastal rivers swimming upstream.

Males remain in brackish waters near mouth → female continue 100’s of mile upriver.

By 8-15 years females >1 M long; return to sea to rejoin males and spawn.

Other spend most of adult life in the sea, and return to
freshwater to spawn

= anadromous

eg. Atlantic species (eg. salmon & steelhead trout)

make spawning runs year after year

eg. pacific species ( sockeye, sliver, humpback & chum salmon)

make one spawning run then die

adults spend 4 yrs at sea yet can unerringly return to parent stream → only a few stray go to wrong stream

when salmon return to site where they were hatched, they spawn and die

the following spring the newly hatched fry “imprint” on the stream as they drift downstream to the sea

How do they find the mouth of the river when they are returning to spawn?

apparently can navigate by orienting to sun’s position

but they can also navigate on cloudy days

may also be able to use earth’s magnetic field

probably also use ocean currents, temperature gradients, food availability to reach general area
annual run of wild salmon today is ~3% of the 10-16 Million fish that ran 150 yrs ago

Salmon runs in Pacific NW have been devastated by stream degradation:

   eg. logging, dam construction (50 dams)

**Preadaptations to terrestrial environment**

**a. Air Breathers**

many fish can survive out of water for a short time by breathing air

   eg. some fish (eg. Anabantoids) can breath air via labyrinithine chamber in head behind gills

   eg. lungs of lungfish & gars

   eg. bowfin (*Amia*) at low temp use mostly gills, at higher temperature use mostly lungs

   eg. some *Corydoras* Catfishes can process air in the hind part of the gut

   eg. freshwater eels commonly make excursions onto land in rainy weather

       do gas exchange through moist skin

   eg. electric eel has degenerate gills and must get most of its oxygen by gulping air

   eg. Indian climbing perch (*Anabas*) spends most of its time on land near water’s edge

       has special chamber above much reduced gills for respiration
can also absorb oxygen from air if skin is moist

e.g. mudskipper can be out of water for long periods but prefers to keep tail in water to absorb oxygen from water through its skin

b. supporting fins

climbing perch
  only climb in wet weather
Fish Life Histories

eels, Anguilla sp

hatch in spring
begin life in larval form, ribbonlike
larvae enter estuaries and bays turn into “glass eels”
transparent but resembling adult
move to freshwaters and live 8-15 years
stay hidden in weed beds ledges or mud during daylight
eat whatever is available
can come ashore searching for food: worms and grubs
can breath through skin
slime layer protects from salinity changes
highly developed sense of smell
light sensitive skin also responds to low frequency sounds
after 10 years in freshwaters, gonads enlarge, fish change shape
and become a bronze or silver eel
eyes enlarge and become more sensitive to light
body fat increases
begin migration to sea to Sargasso sea
need fairly high water temperatures to reach sexual maturity
large eel can produce 2.5 Million eggs

Toothpick fish (Candiru)

parasitic freshwater catfish in Amazon river
eel shaped, translucent → impossible to see in water
up to 6” (15 cm) long
most feared fish in these waters, more than piranha
they can detect respiratory currents and swim toward gill openings of other fish where they feed on prey’s blood
some species lie in wait in murkey bottom mud
sample water for nitrogen wastes from gills of fish
eg. ammonia, urea

once detected they dart towards the gill cavity with a burst of speed

once inside gills they lodge themselves in place with its spines

gnaws a hole toward a major blood vessel and gorges itself for a few minutes only

it then dislodges itself and sinks back to bottom of river to digest its food

victim usually bleeds to death

is known to attack people and swims into an orifice; vagina, anus, penis

locates its target when people urinate near the fish

has been known (and videotaped) swimming up a urine stream into penis of victim

almost impossible to remove without surgery
Human Impacts of Fish

**Pets**

20 million fish are sold each year as pets in US alone

**Commercial Fisheries**

**marine fisheries**

marine food sources (including fish) provide about 25% (directly and indirectly) of animal protein

commercial fishing employs 200 Million people worldwide

2.6 billion people worldwide depend on fish for protein (2002)

60% of all fish consumption is by the developing world (2008)

estimates suggest that seafood production from wild fish stocks will not be sufficient to meet growing world demand in the next century

global production from fishing and aquaculture

1999-2001 \( \rightarrow \) 93 million tonnes

2002 \( \rightarrow \) 133 million tonnes

total marine fish catch has peaked at about 100
Million tons and remained stable, in spite of increased efforts to catch fish.

Most commercial fisheries are near shore where most pollution and damage occurs.

Open ocean catch has been increasing:

~ 11% of total (2002)

Per capita (per person) fish catch is decreasing as population expands.

11 of the world's 17 major fisheries are overfished and in decline.

Estimates that ~ half of all commercial fisheries stocks are "fully exploited" and another quarter are overexploited, depleted or slowly recovering.

→ Most conclude that global marine fish production is not sustainable at the current levels.

Subsidies encourage overfishing:

World spent $124 billion to catch $70 billion worth of fish, the difference was paid for by taxpayers.
of the world fish catch only two thirds are used directly for human consumption,

the rest is converted to fish meal and oil,

and pet and livestock food

much of what is collected is wasted as “bycatch”, especially in industrial countries,

examples:

shrimpers typically discard 1 to 8 times as many creatures than they keep

gulf of mexico shrimpers killed 34 million red snapper and over 3000 sharks in one year

open ocean fishermen use large drift nets (25’deep and 50 miles long), set out 30,000 miles of net a night worldwide;

18 miles of net is lost per night,

1000 miles per year become ‘ghost nets’ and trap and entangle fish for decades as they float in the ocean

these nets killed 42 million seabirds, marine mammals and other nontarget animals
increase in **biomass fishing**:  
→ collecting all life in an area and grinding it up for meal, used as feed for fish farming  
  decimates communities in an area

**freshwater fisheries**

fish from inland waters accounted for 10% of total catch (2002)

many river basins, especially in developing countries support intensive fisheries

inland fish are considered to be the most threatened group among all vertebrates used by humans

**Aquaculture**

fastest growing animal protein sector 
  especially in developing countries 

contributes almost 1/3\textsuperscript{rd} world supply of fish products

China and other Asian countries are the largest producers

aquaculture produces more than 220 species
carp are the largest group