ADAPTATION TO FRESH WATER HABITATS

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A. Freshwater habitats and biota

B. Ionic and osmotic adaptation and water balance

C. Thermal adaptation

D. Respiratory adaptation

E. Reproductive and life-cycle adaptation

F. Mechanical, locomotory and sensory adaptations

G. Feeding and being fed on

H. Anthropogenic problems

A. Freshwater habitats and biota

- Salt concentrations between 0.01 and 0.5 ppt, i.e less than 1% of sea water.
- About 3% of all water is fresh, **habitable volume of liquid fresh water is less than 1%**, as two-thirds of the total 3% is permanently frozen in polar ice caps and glaciers.
- Of that 1% free fresh water, only about **0.1% of all the Earth's water is "visible" liquid fresh water**, as lakes, ponds, and rivers (rest as underground aquifers or within soils).
- An even smaller percentage of the planetary water is within the biosphere at any one time (?).

Fresh water is of great biological interest

1. **The high overall water availability** (exceptionally productive floodplains and river deltas). Make up only 3% of the terrestrial surface of the planet but account for 12% of the “land-based” productivity.

2 **The habitats are highly variable**, of many types, of tremendous chemical variability than any other type of habitat, **no two freshwater bodies are ever quite the same**.

3 Act as an important **driving force**, cycling minerals and nutrients around the terrestrial environment, via the **hydrological cycle**.

4 Impinge on human activity considerably, since settlements have always been concentrated alongside rivers and lakes.

5 Humans also impinge on the freshwater zones very considerably they are the central cause for concern in environmental study and conservation.

Natural water has varied physical and chemical characteristics with patterns of temperature, pressure, ionic strength and pH

Surface fresh waters can be

Moving, or lotic waters (rivers, streams, and temporary trickles)

Shows length-wise zonation

Still, or lentic waters (lakes, pools, puddles, and rain drops, also bogs, fens, marshes, swamps (wetlands), and even damp soils, moss cushions, etc.

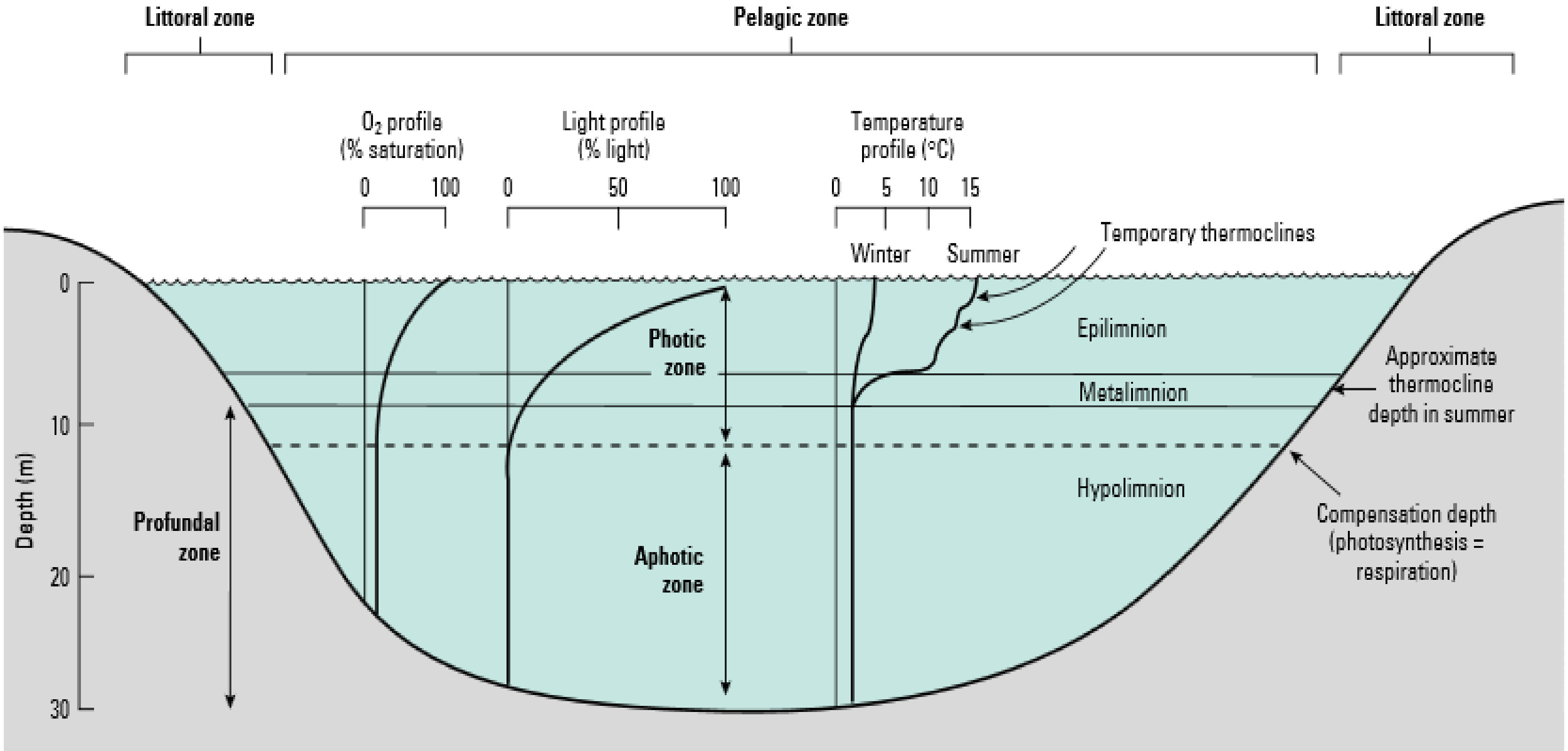
No length-wise zonation, but shows **stratification**

Thermal stratification (Thermocline): Epilimnion, Metalimnion & Hypolimnion

Oxygen stratification (Oxycline)

Photic stratification: Photic zone & aphotic zone

Nutrient stratification: Oligotrophic, mesotrophic & eutrophic



Patterns of stratification in lakes, showing the deep hypolimnion and superficial epilimnion in relation to temperature profiles and oxygenation

Relative success in freshwater habitats for different taxa (in terms of number of species)

	Very abundant	Moderate	Absent
Algae	Chlorophytes	Other algae	
Plants	Angiosperms	Bryophytes	Conifers
Animals	Crustaceans (ostracods, cladocerans) Rotifers Nematodes Oligochaetes Gastropods Insects Teleosts	Planarians Bryozoans Bivalves Tardigrades Other vertebrates	Echinoderms Cephalopods

In all fresh waters, invertebrates tend to dominate the benthos and fish dominate the open water

B. Ionic and osmotic adaptation and water balance

- Freshwater animals face the central problem of a permanently dilute external medium, with Na, K and Ca levels often below 1 mM, with a permanent gradient for ion loss out of their bodies and a net inward osmotic flux of water, so that they must continuously counteract a tendency to become diluted and to swell up.
- Freshwater dwellers are all capable of osmotic and ionic regulation, as it is impossible to maintain functioning tissues at these continuously low conc.

- Two factors vary and tend to be interrelated:
  - Level of body fluid concentration maintained in fresh water itself (commonly 0.1–5 mm), and
  - The tolerance range

All these animals exhibit:

- ❖ Reduced permeability
- ❖ Ion uptake mechanisms
- ❖ Cellular osmoregulation with small osmotic effectors
- ❖ Regulated hyposmotic urine

Permeability

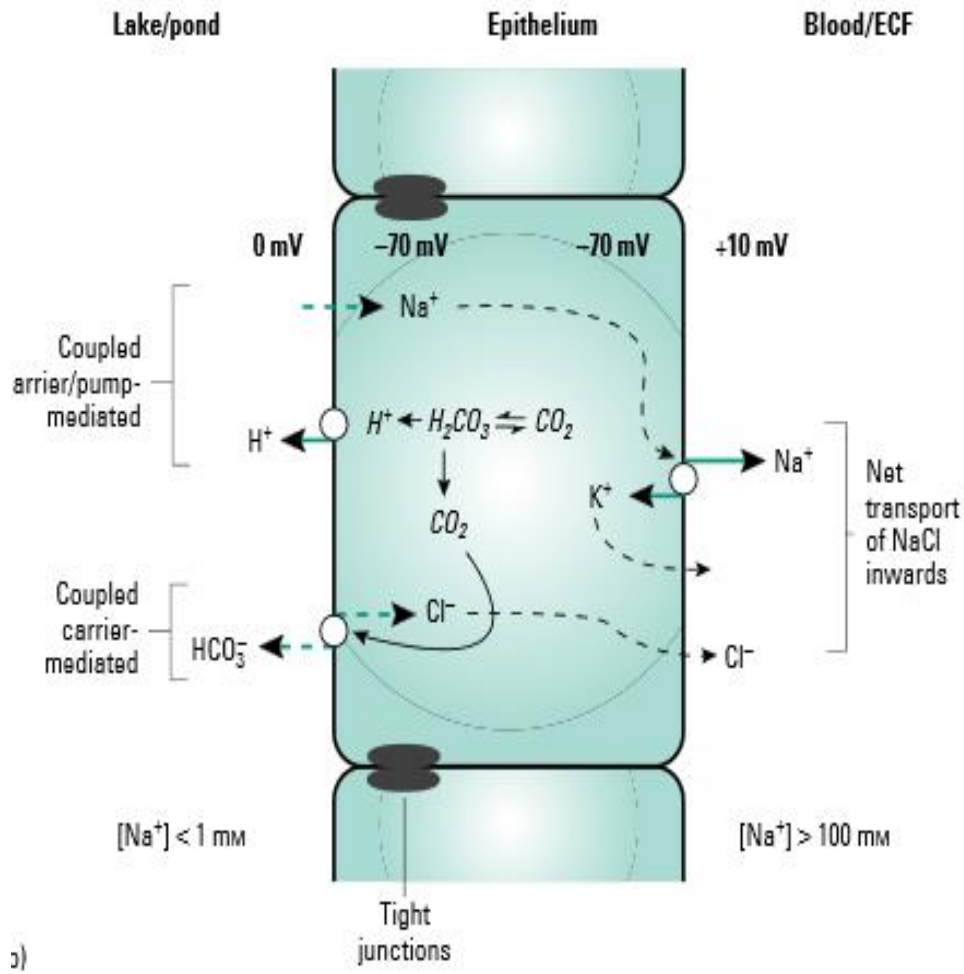
- The permeabilities to water and to sodium (P_w and P_{Na}) for both invertebrates and vertebrates is much lower than for marine animals.
- But there will still be substantial osmotic gain of water and diffusional loss of ions, due to the relatively large gradients involved.
- The larva of a mosquito (*Aedes*) may gain 3% of its total body water volume per day osmotically, and for the crayfish *Astacus*, with more concentrated blood, it is 5%.
- Amphibians show relatively high permeability, but also show an unusual ability to control P_w, particularly in the region used for water uptake known as the "**pelvic patch**", a section of ventral abdominal skin.
- When dehydrated, or when the bladder is empty, *Bufo* produces the hormone arginine vasotocin increasing P_w in this area.
- A second hormonal axis, the renin–angiotensin system, controls the water uptake rate in the same patch.

Comparative values of water permeability (P_w) and sodium permeability (P_{Na}) in brackish, marine and freshwater species

Habitat	P_w (10^{-4} cm s^{-1})	P_{Na} (10^{-6} cm s^{-1})
Brackish water	*1.3 to* 3.8	4.0 to 5.7
Sea water	9.0 to 12.9	5.0 to 13.0
Fresh water	0.22 to 3.9	0.4 to 0.8

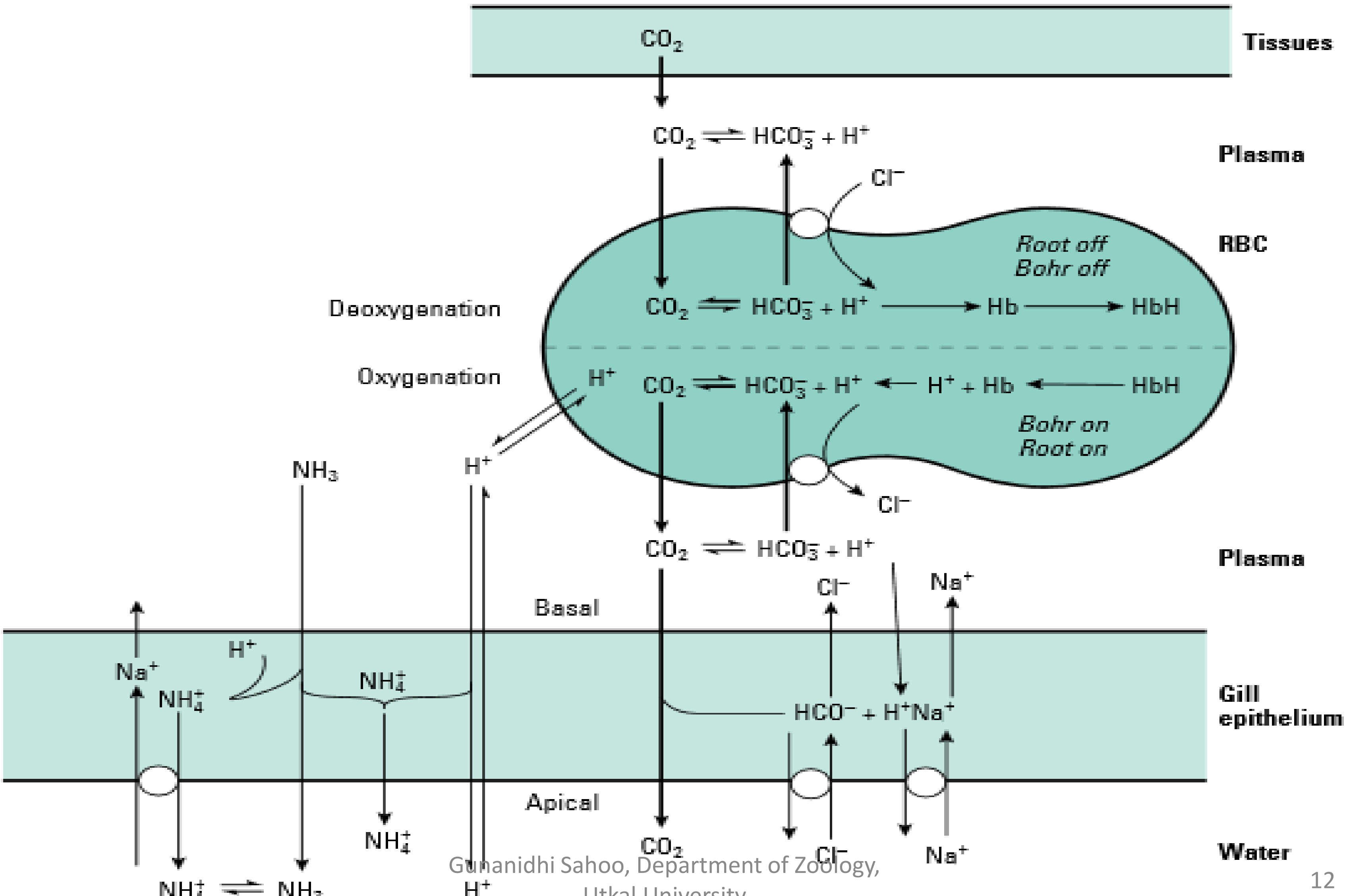
Ion uptake: is commonly centered on the skin, or on the gills in fish and in invertebrates such as crustaceans and insects.

An apical ATPase pumps H^+ ions out of the cell, providing a steeper electrochemical gradient for Na^+ entry (so that Na^+/H^+ exchanges are indirectly coupled), and a more direct Cl^-/HCO^-_3 exchange also occurs; overall the effect is an apical electroneutral (1 : 1) ion exchange. This is followed by active basal ion transport via the sodium pump, the counter-ions (H^+ and HCO_3^-) being provided by CO_2 from the body fluids.



The basic pattern of ion uptake in freshwater gills or skins

Interaction of ion transport, CO_2 movement and NH_3 excretion across a freshwater fish gill



Osmolytes and cellular regulation

- Strictly freshwater invertebrate animals cannot afford to accumulate large amounts of intracellular organic osmolytes (=compounds affecting osmosis), so that cellular osmotic regulation by variation of levels of free amino acids is relatively unimportant to them.

- They tend to regulate their volume using movements of potassium ions from cytoplasm to extracellular fluid, thus reducing osmotic intake and resultant swelling, allowing a suitable electrochemical balance to be maintained.

- For example, volume regulation in the bivalve *Dreissena* fails if potassium is unavailable, and the ideal ratio of K^+ to Na^+ in the surrounding medium is around 0.01.

Hyposmotic urine

Most **marine and brackish-water invertebrates** have unmodified, isosmotic urine.

But **freshwater forms**, (continuous influx of water through their external surfaces and also usually an unavoidable input of fresh water as they feed) often show the additional strategy of recovering ions from their urine to leave it distinctly **hyposmotic** to themselves (urine : blood ratio < 1).

The mechanism is essentially the same as ion uptake in gill or skin epithelia, but involves ion resorption from the urine filtrate back into the body.

Classic examples of the structures involved are the **flame cells, nephridia, Malpighian tubules, vertebrate kidneys, etc.**

Leeches are an unusual case (predominantly live in fresh water, occasionally moving around on land and having the additional problem of intermittent blood meals.

Their primary urine is formed in multiple paired nephridia tubules by a combination of ultrafiltration from the blood system and a secretory process based on chloride transport from special canalicular cells in the upper tubules. The lower tubule then normally resorbs 85% of Na^+ and 97% of K^+, forming a very hyposmotic urine.

Other ionic problems

- Regulation of ions other than Na & K can be crucial in freshwater bodies, which may be individually peculiar in composition.

- In particular, exposure to high or low pH regimes (anthropogenic acidification) causes new problems for water and ion regulatory systems.

- Acidic habitats disrupts electrolyte balance in both invertebrates and vertebrates, primarily by inhibiting active Na uptake and increasing diffusional Na loss.

- **Sluggish animals** (bivalves): Low pH and much reduced PO_2 in blood, redressed in a few days by mobilizing bicarbonate from the shell.

- **More active animals**: Achieved by varying ventilation patterns to change the availability of CO_2, which provides the counter-ions for NaCl uptake, giving a degree of automatic feedback.

- Insects – molting - abnormally dilute hemolymph and calcium deficiency --period of intensive postmolt branchial (gill) NaCl uptake, with additional branchial uptake of Ca^{+2} and HCO^{-}_3 using a Ca^{+2}-ATPase and Ca^{2+}/Na^{+} exchange. In insects, the gut helps as a reserve for ions and water during the molt.

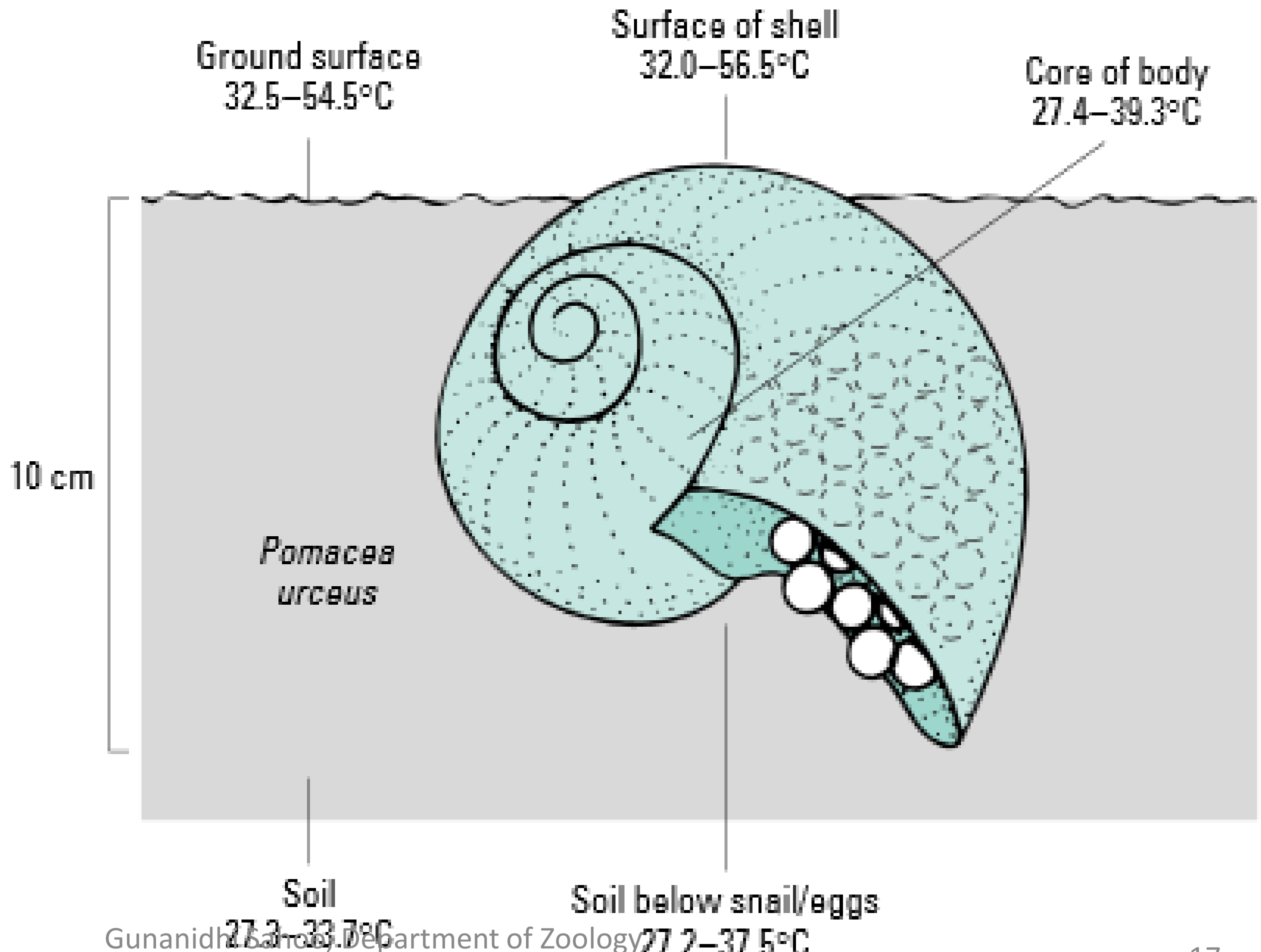
C. Thermal adaptations

- In most cases, T_b matches the water temperature.

- Others (some motile animals) use a limited degree of behavioral thermoregulation.
- Tadpoles may **select warmer water at the edges of ponds**, and may shuttle in and out of the warmer waters to maintain a fairly constant T_b .
- Certain small freshwater fish, and *Hyla* tadpoles, show "**basking**" behaviors in these shallow water edges, orientated to the sun.
- Many semiaquatic animals like alligators use basking to control T_b ; **move into shallow water to warm up**, may also expose part of their backs to the air to allow drying. If T_a is high enough they bask on the river bank.
- Water snakes also bask out of the water, especially in the early morning, returning to water around midday.
- Some freshwater ectotherms show **thermal preferences** (T_{pref} or "eccritic temperatures") wherever there is a **gradient of available temperature**, for example from deep water to shallow or from midstream to unstirred edges.

Amphibious animals face varied rates of cooling according to whether they are in air or water. Small invertebrates aestivate during summer drought, snails bury partially in pond mud. The turtle raises its T_b by basking in water or in air, and lowers it by immersion.

Temperature balance in a freshwater swamp snail, during aestivation at the mud surface. The snail's body and its eggs remain below 40°C though the shell surface may reach 56°C.



Coping with freezing

- Freezing is a significant problem for temperate freshwater ectotherms.
- In moderate- to high-latitude lakes the bottom water never freezes and may stay at 4°C protected by insulating snow and ice above.

- Freshwater animals tend to show little accumulation of colligatively active solutes, and supercool only moderately (−5 to −7°C compared with −10 or −20°C in many terrestrial invertebrates from similar latitudes) and try not to encounter any ice.
- Certain species of turtle can survive a degree of freezing, at least for a few hours.

- Freshwater invertebrates in high latitudes may suffer seasonal freezing; many may migrate away from a freezing front in a stream, or burrow deep enough to avoid actual freezing, whole communities of insect larvae do become frozen within the gravel.

Freshwater endotherms

- Limited to secondarily invading birds and mammals.
- Most are amphibious, swimming on the water surface (ducks, etc.) or diving beneath the water in search of food (sea cows and river dolphins are permanently aquatic). There are no partially endothermic freshwater fish, nor are there any known cases of freshwater insect endotherms.
- The main problem for an aquatic endotherm is not with heat generation but with heat retention, the animal being surrounded by a more conductive medium that is below the body temperature, into which heat is rapidly dissipated. Insulation layers (fur and feathers) are thus critical.
- This raises the problems of **wetting** (reduces the insulating value of such layers substantially by replacing the trapped air with water as well as compressing the fur or feathers.
- Birds solve this by oil glands (reduce their wettability, an air layer trapped against the skin; this has a substantial buoyant effect.
- Mammals achieve a similar insulating effect with an underfur that retains an air layer, or may use the normal dense fur to trap a layer of stagnant water that at least reduces convective heat loss.

D. Respiratory adaptation

Several factors can reduce the available O_2 in the water column of rivers and eutrophic lakes:

1. Seasonal cycles of productivity and vegetation decay: anoxia in the hypolimnion and potentially supersaturation in the epilimnion.
2 Raised temperature: in spring and summer lakes may lose up to 50% of their oxygen simply due to temperature change.
3 Prolonged freezing: below the ice all the oxygen may get used up and it is not renewed until the spring melt.
4 Build up of water weeds in high-nutrient zones.
5 Flow patterns where rainfall is highly seasonal.
6 Benthic muds of still waters and in most wetlands such as marshes and swamps, tend to be rather anaerobic.
7 Human interference

The most obvious and widespread solutions to variable oxygen supply are three-fold:

1 To expand or elaborate the respiratory surface.

2 To use higher affinity oxygen-storing pigments.

3 To modulate the ventilatory and/or circulatory rates.

1_ Respiratory surfaces

Most freshwater soft-bodied invertebrates are derived from marine ancestors already endowed with aquatic respiratory systems.

Most annelids and molluscs retain the cutaneous exchange surfaces, or serially repeated filamentous gills or tentacular crown gills, or enclosed lamellate gills, of their relatives.

In specialist benthic animals, such as oligochaetes, the head is buried in mud and the skin of the posterior half of the body is particularly well vascularized.

The wetland oligochaete *Alma* has a particularly deeply grooved tail with dense vascularization.

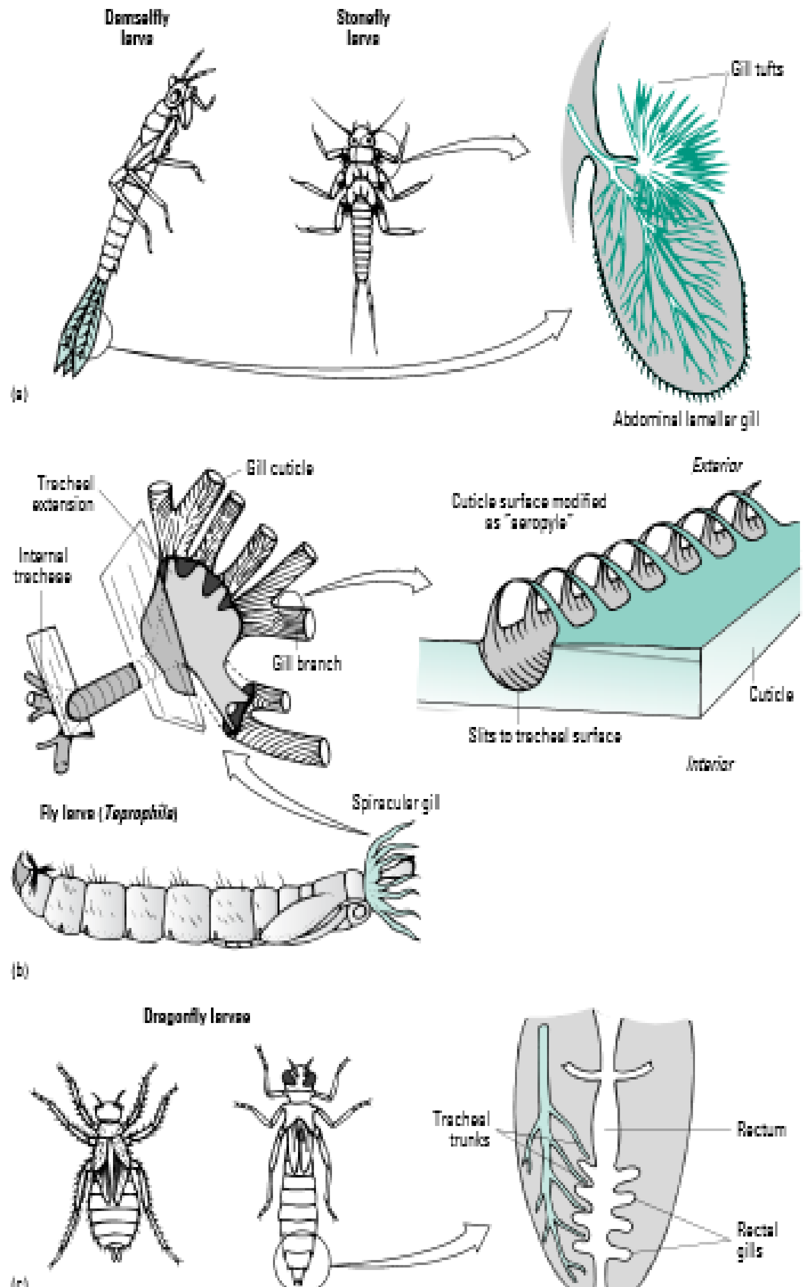
Use of different exchange sites in different conditions also occurs:

- The common pond snail, *Lymnaea stagnalis*, has 25% cutaneous uptake at low Po_2, but this can rise to 50% as Po_2 rises.
- The snail *Biomphalaria* has both gills and lungs.

Fully aquatic freshwater insects: addition of **cuticular gills**

a. Many larval forms have tracheal gills - extensions of the body surface contain a dense network of tracheae eg., stonefly, mayfly
b. Some have spiracular gills a tube-like structure extends from a spiracle.
c. Still others have rectal gills with tracheoles investing folds of the rectal surface eg., Dragon fly larvae.

Amphibious insects: breathe from air stores when under water.



Freshwater vertebrates may use cutaneous or gill-based respiration, or reliant on aerial supplies via lungs.

Skin-breathing is quite common in freshwater fish larvae and many eels.

Swamp-dwelling fish like the bichir (*Polypterus*) and the **lungfish** (*Protopterus, Lepidosiren* and *Neoceratodus*) show the **development of lungs from the swimbladder**.

Some catfish and bowfins develop less specialized **vascularized swimbladders** or gut regions.

Some salamanders show a high dependence on **cutaneous oxygen uptake**. Certain adult frogs have highly vascularized and folded areas of **skin/"hairy" skin**, that contribute a large part of their O_2 requirement, only using their lungs when active or if exposed to hypoxic surroundings.

Most fish and juvenile or neotenous amphibians, use gills and nearly all adult amphibians and reptiles, birds, and mammals (secondarily aquatic) rely on air-breathing through lungs.

The surface area in freshwater mammals (porpoise, dugong) show higher uptake rate than predicted.

2. Respiratory pigments

Increased exploitation of pigments as O_2 carriers and stores in fresh water invertebrates, many species are red or green in general color.

- Pigment characteristics vary with habitat and lifestyle.
- In the blue crab, *Callinectes*, hypoxia is accompanied by an increase in the amount of circulating hemocyanin, but also a shift in the hemocyanins in the blood, with more of the high-affinity 1×6-meric oligomer and less of the normal 2×6-meric oligomer.

The properties of the hemocyanin also vary in relation to both temperature and ionic strength of the blood.

- Goldfish acclimated to different temperature regimes show complex responses involving erythropoiesis, loss of existing RBCs, and division of circulating juvenile RBCs, thus adjusting the abundance of hemoglobin isomorphs without greatly affecting overall hematocrit and blood viscosity.
- Mobilization of stored RBCs provides another safety valve.

3. Ventilation and circulation

Increased ventilation rate: first and quickest response to changing oxygen demand in freshwater animals.

- In small animals (sponges & rotifers), ventilation is mainly by cilia or flagella, whose activity increases as needed.
- In invetebrate bottom-dwellers it may involve wiggling of the whole body, or localized bursts of gill activity in many insect larvae.
- Molluscs and crustaceans tend to have baling systems and use either an increase in rate or in stroke volume, or both, as Po_2 declines.

- Fish employ modulation of both stroke volume and frequency (by varying the buccal and opercular pumping patterns) to match oxygen uptake at gills to demand, as detected by oxygen receptors that are usually sited in the brain and aorta.
- The green turtle shows a seven-fold increase in mean ventilation frequency and increases in both pulmonary and aortic blood flow.

E. Reproductive and life-cycle adaptation

Key problems in freshwater habitats that influence reproductive strategies:

1. **The transience and changeability of the habitat**: require opportunistic breeding carefully tied to seasonal change, and a protected stage in the life cycle.

2. **Physiological difficulty of maintaining ion and water balance**: much more difficult in small animals such as larvae and juveniles with a high surface area to volume ratio.

3. **Continuous down-stream flow in streams and rivers**: problem of countering, especially for small or immature individuals.

- General tendency in freshwater invertebrates:

  - to have very short life cycles with a rapid turnover of generations,

  - to reduce larval forms, with more direct development, larger and yolkier eggs (many molluscs) or brood pouches (water flea, *Daphnia*).

  Where larvae persist they tend to be either unusually **large**, or to adopt a **crawling habit**, or to have **protected surfaces**, or in a few special cases to become **parasitic** on larger animals such as fish (veliger larvae of *Unio* grow in the gills of various fish).

- More species use **direct insemination**, or protected spermatophores, protective "dormant" stages (gemmule, encysted eggs, cocoons).

- Very high annual reproductive output in freshwater invertebrates.

Adaptations include:

a. Short life-cycle strategies
b. Long life-cycle strategies
c. Phenotypic plasticity and polymorphism
d. Life cycles of freshwater vertebrates

a. Short life-cycle strategies:

Ex - Many of the zooplanktons.

Rotifers and cladocerans complete their lives in just a few days, produce many generations per year (**multivoltine**); mature quickly and put most of their assimilated energy into gamete production.

Finding a mate (time-wasting process) is avoided by parthenogenesis, only females are produced.

A brief phase of production of sexual morphs usually occurs in the fall, or as drought sets in.

b. Long life-cycle strategies

Most copepods, insects and benthic invertebrates are univoltine; grow relatively slowly through many molt cycles, usually do not show parthenogenesis and rather less frequently use dormant stages.

Annual reproductive output in these longer lived animals is lower (though it may still be high compared to other habitats).

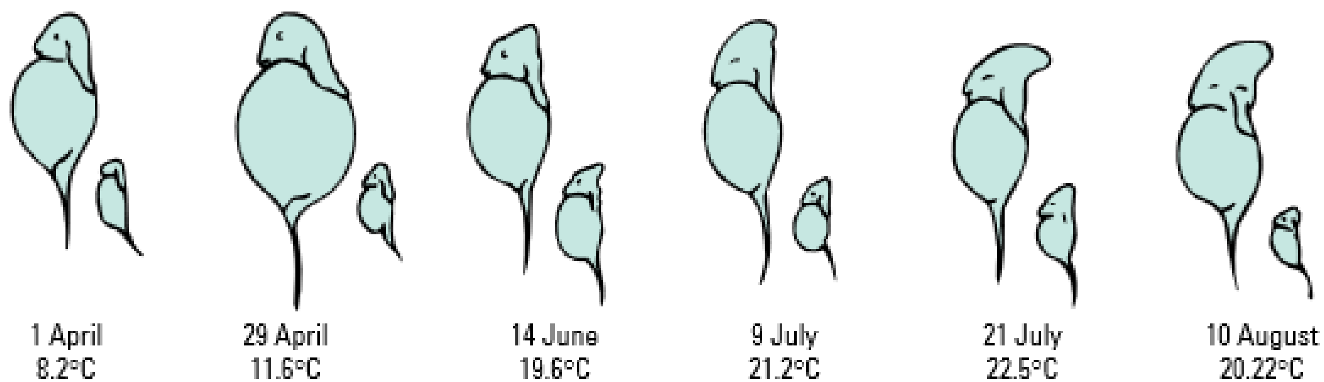
- Lotic waters are particularly hazardous for free gametes and for pelagic larval stages, which would move downstream freely, hence rarely found. Instead lotic invertebrates use **internal fertilization, the young are retained in the body, or large yolky eggs are firmly cemented to the substrate**.

c. Phenotypic plasticity and polymorphism

Broad life-history strategies, may be accompanied by a pronounced degree of **phenotypic plasticity**, allowing the reproductive output to vary with environmental conditions.

In *Daphnia*, water temperature has a clear effect, with **larger size at maturity** when **water temperatures are lower**.

- The well-known phenomenon of **cyclomorphosis** occurs in many parthenogenetic freshwater animals, where generations are polymorphic in form, physiology, or behavior, or all of these.
- A classic case is again the water flea *Daphnia* and in some rotifers.



Cyclomorphosis in *Daphnia*; young and adult morphology at different dates from a temperate pond, showing the progressive growth of the "helmet" after successive molts.

Resource-based or trophic polymorphisms involving differences in life-history strategy

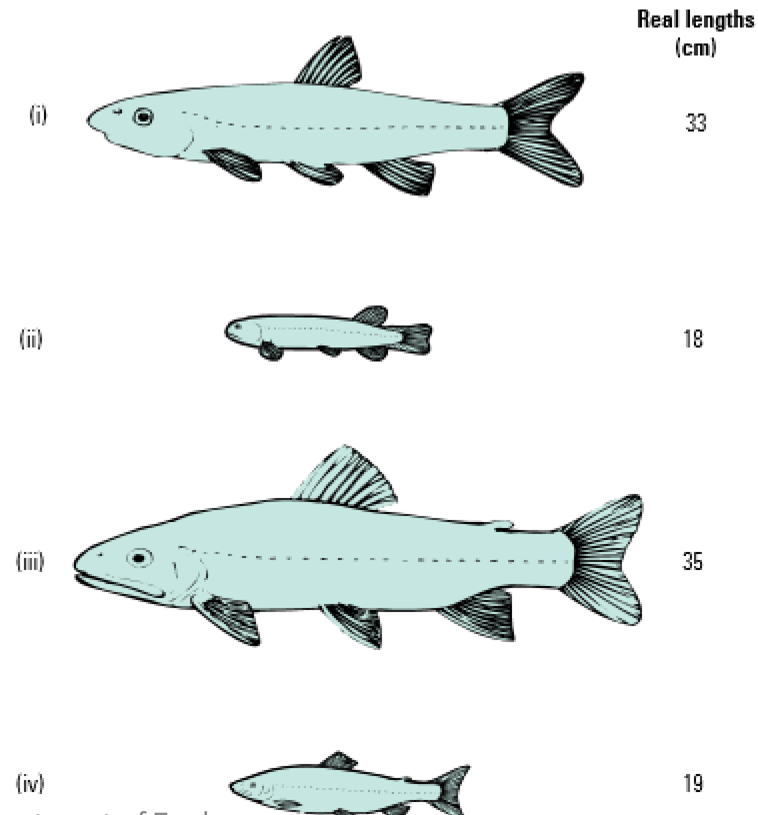
The four morphs of Arctic charr (*Salvelinus alpinus*) from an Icelandic lake:

(i) Large benthivore

(ii) small benthivore

(iii) Piscivore

(iv) planktivore



d. Life cycles of freshwater vertebrates

Reproduction in **freshwater fish** shows similar patterns to invertebrates.

Eggs may serve as a protected stage for seasonal endurance. Freshwater fish eggs are generally larger (1–30 mm dia) than marine fish eggs (0.8 –2 mm), and may be protected in mucus froth “nests”, or in vegetation.

Where a pond or stream dries up, the eggs may survive in the bottom mud.

Secondary freshwater vertebrates usually resort to a terrestrial site for reproduction.

- Some turtles on the upper shore. Some other turtles lay eggs in mud under shallow water, but these stay in developmental arrest until the water recedes and oxygen is able to diffuse into the embryo.

F. Mechanical, locomotory, and sensory adaptations

Depth, buoyancy, and locomotion

- Fresh water is rarely very deep, (Baikal- only 1000–1500 m), No great pressures.
- Buoyancy is more difficult in fresh water due to the **reduced specific gravity** of the medium giving very little lift. The body must be more spiky or frilly to increase the drag forces, or more oil or gas must be included within the tissues.
- In fish the swim-bladder is present in a much higher **%** of species and is larger, about 6 –9% of body volume in freshwater teleosts compared with only 4 –5% in marine species.
- Locomotion is not a problem in standing water. In lotic habitat, **suckers and hooks** for adhesion may be appropriate for bottom-dwellers; **byssus threads** for adhesion in freshwater bivalves.
- In moderately fast flow, a **streamlined shape** flattened against the substratum ensure stability, as the fast water flow over the upper surface effectively presses the animal down and keeps it in place.

Senses

Vision:

- In general lentic environments are well lit through most of their depth, and only deep lakes extend beyond the photic zone.
- Light may get depleted by vegetation. Eyes need to work in dim conditions. Have **large facets or large pupils**.
- **Rhodopsins are sensitive to green wavelengths**, filtering through the floating or shading foliage.
- Amphibious sps have **two sets of eyes** that focus simultaneously on a terrestrial and an aquatic image.
- Diving mammals and birds that hunt by swimming beneath the water must be able to accommodate their eyes by **altering the lens–cornea relationship** using the **ciliary muscles**.

Chemoreception

- Important to many freshwater animals for prey location, predator avoidance, and the location of hosts or mates.

  Teleosts have good **acid, alkali, and salt receptivity**, and the minnow can detect 10^{-5}m sucrose or 4×10^{-5}m NaCl.

  Also **specific sensors for intraspecific cues**, such as the alarm substance released from the skin of damaged individuals.

Mechanoreception

Many aquatic insects have **water pressure (= depth) receptors**.

- Bugs with relatively long bodies use pressure sensors adjacent to their abdominal air spaces to detect differences in tracheal pressure between each segment.
- **Flow receptors** are also critical for lotic species, and are designed from deformable neuroepithelial cells or from hair cells.
- In larger animals (crustaceans & fish), the receptors may be associated with cephalic appendages such as antennae or vibrissae.

G. Feeding and being fed on

1. Microphagous feeding
2. Herbivory
3. Carnivory
4. Feeding and growth patterns
5. Avoiding predation

1. Microphagous feeding

- Most of the freshwater zooplankton are **filter feeders**, exploiting the algae, bacteria, and detritus in the water column.
- Some are **generalists**, but many are **highly selective**, taking particular kinds of green algae, diatoms, or flagellates.
- Cyanobacteria are generally avoided.
- Benthic invertebrates feed on the sinking remains of algal blooms, particularly the diatoms, which remain fairly intact as they sink and are a rich source of fatty acids.
- True detritus feeding (swallowing the mud, in effect) is practiced by oligochaete worms (*Tubifex, etc.).*
- Grazers are abundant in benthic communities scraping microbial communities (the **epiphyton**) off rocks and plants fairly nonselectively.

- **Thus all the vegetation that dies within a freshwater body eventually becomes a food source.**

2. Herbivory

- Herbivory (papyrus and water hyacinth) is common in parts of the tropics, where large grazers such as hippopotamus, water deer and dugong are important.

- Relatively rare in temperate systems, since there are few macrophytes in many lakes.

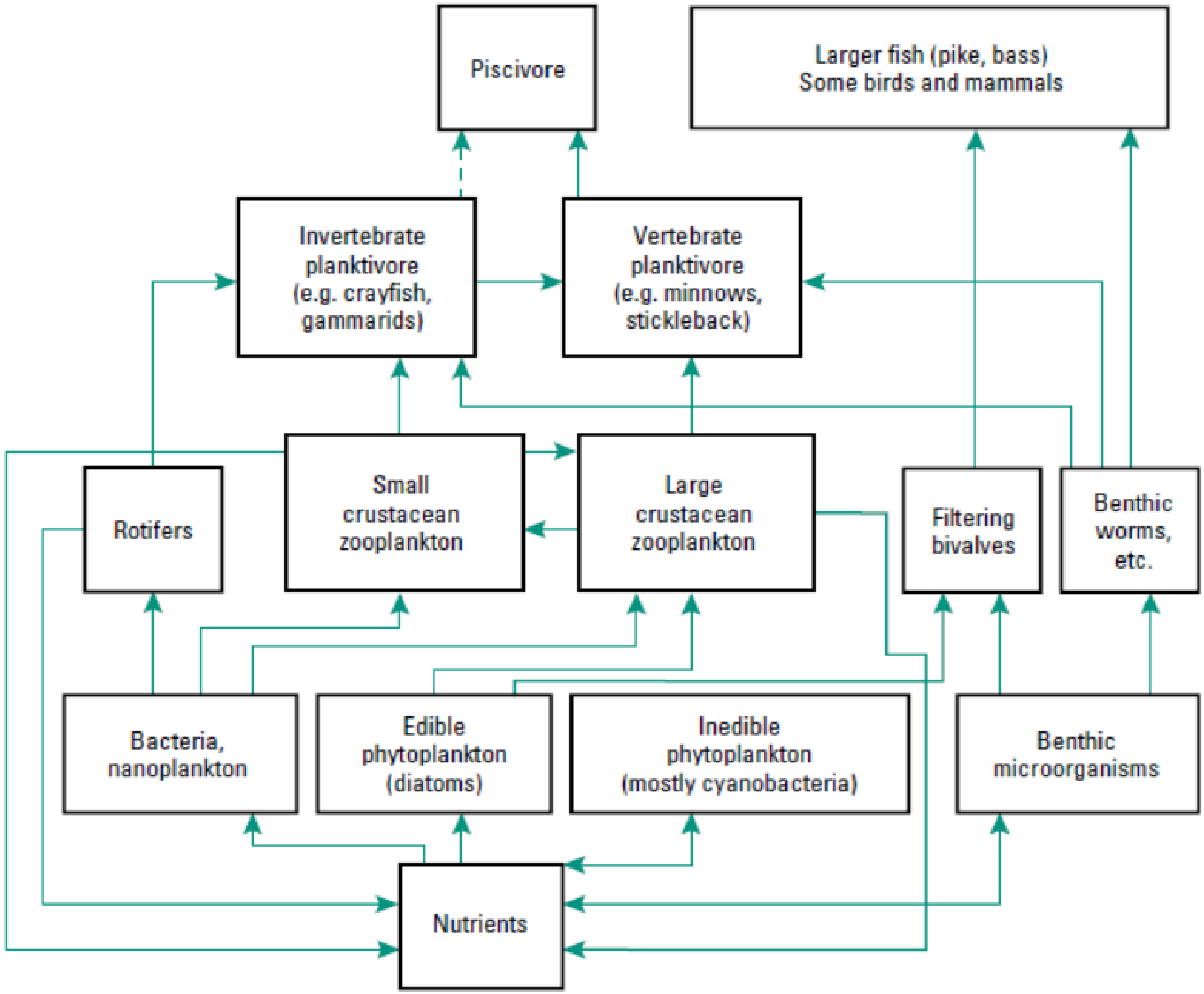
3. Carnivory

Either **lurkers** (wait in concealment)or **hunters**.

Stationary lurking by *Hydra,* Leeches, stonefly and alder fly larvae.

Predatory hunting is also common amongst insects and almost ubiquitous at some point in the life cycle of fish.

Some species of **alligator** have the **most acidic stomach contents** yet discovered, and are able to break down and digest even the bones of their prey.



The trophic web in a typical temperate lake

4. Feeding and growth patterns

- **Diel and seasonal patterns** of food abundance in fresh water have a major effect on growth patterns, which in some parts of a season may be strongly negative.
- The freshwater flatworms can undergo extraordinary degrees of starvation, reducing their body mass to as little of 1/300 of its maximum and resorbing most of their gut and parenchyma.
- **Seasonality** is also very strongly influential on patterns of feeding activities.
- Many components of the zooplankton show **vertical diurnal migrations**, and planktivorous carnivores must move with them.
- In temperate lakes there are commonly "**spring blooms**" at times in two phases. Fish populations inevitably are trophically linked to these blooms.

5. Avoiding predation

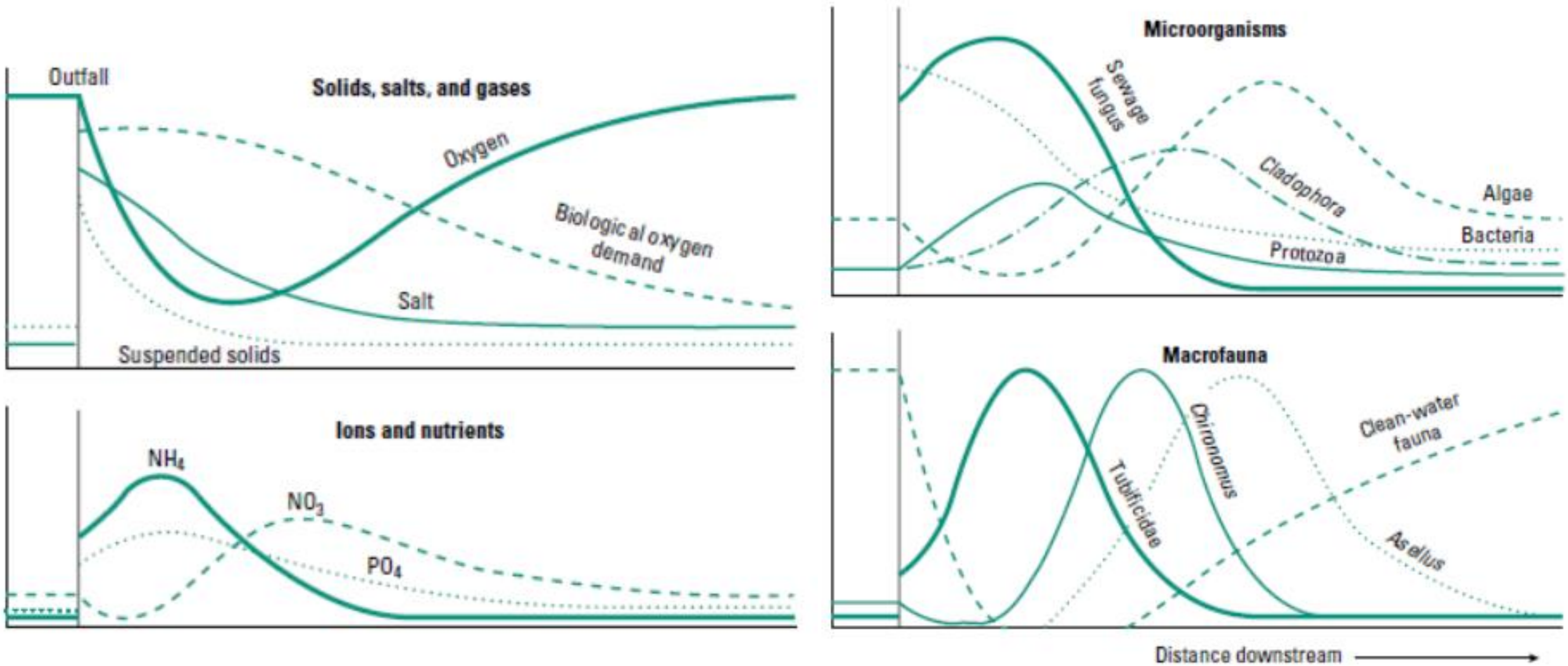
- Diurnal movements.
- Cyclomorphosis
- spines, helmets, and other protuberances produced seasonally by cyclomorphic rotifers and cladocerans may be a defense against invertebrate predation.
- Good attachment systems, strong molluscan shells with appropriate resistance to boring mouthparts, and surface prickliness in larger animals.

H. Anthropogenic problems

Type	Source
Acids and alkalis	Industrial
Anions (S^{2-}, SO_3^{2-}, CN^-, etc.)	Industrial, mining
Detergents	Industrial, domestic
Sewage	Domestic
Silage and farm manures	Agricultural
Food wastes	Domestic, agricultural
Gases (Cl_2, NH_3, etc.)	Industrial
Heat	Industrial, power generation
Metals (Cd, Zn, Pb, Hg)	Mining, industrial
Nutrients (nitrates, phosphates)	Agricultural
Oil and oil dispersants	Industrial
Organic toxins (C_6 residues)	Industrial
Pathogens	Various
Pesticides, herbicides	Agricultural
Polychlorinated biphenyls	Shipping, tourism
Radionuclides	Industrial, power generation

Categories of wastes discharged into fresh waters.

Effects of effluent discharge in a river: downstream patterns of physical and chemical change, and the associated changes in microorganisms and macroinvertebrates



Pollution susceptibility in freshwater animals (1 = resistant, 10 = highly susceptible)

Category	Animal taxa
1	Oligochaeta
2	Chironomid larvae
3	Most pond snails; most leeches; water louse *Asellus*
4	*Baetis* mayflies; alder flies; fish leeches
5	Most bugs and beetles; crane flies; blackflies; flatworms
6	*Viviparus* pond snails; mussels; gammarids; some dragonflies
7	Some mayflies; some stoneflies; most caddis
8	Crayfish; most dragonflies
9	Some dragonflies
10	Most mayflies and stoneflies; most caddis; river bug *Aphelocheirus*