

## IONIC & OSMOTIC REGULATION

The life originated in sea, so most of the animals have body salt concentration similar to seawater. In due course the life diversified to different environments to avoid competition. The organisms got adapted to i) live in fresh water, ii) to highly saline water, iii) Estuaries, iv) Terrestrial living whereas some animals showed migratory behaviour - migrating from sea to river & back.

Due to this type of diversified living they started facing problems of ionic & osmotic regulation i.e. regulation of salt & water contents respectively. According to composition of environment in which the animals are living can be grouped into 4 categories

- (i) organisms living in isosmotic environment [living in sea]
- (ii) organisms living in hyposmotic environment [living in freshwater]
- (iii) organisms living in hyperosmotic environment [living in high salinity water]
- (iv) organisms living on land – Terrestrial living.

### **Ionic & osmotic problems of iso-osmotic living**

All the marine organisms are said to live in isosmotic environment because the composition of marine water & that of cell cytoplasm are such that the osmotic pressure is equal on either sides of cell membrane. Hence it is felt that the organisms will not face water & ionic regulation problems. However it is not true. The animals have characteristic salt composition in their tissues, which is different than the seawater, & hence they have to struggle to maintain it to constant.

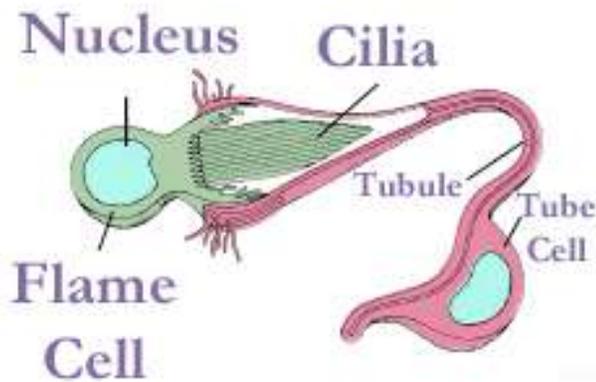
So also in the body of animals metabolic activities are going on due to which metabolites accumulate in cell leading to change in osmotic pressure. Due to which water enters in. when the excess water is given out by the cells some salts are lost along with it & the cells have to make up the loss. Thus even in isoosmotic environment the organisms have to carry on ionic & osmotic regulation. However the organisms try to minimize these problems by developing different type of mechanisms.

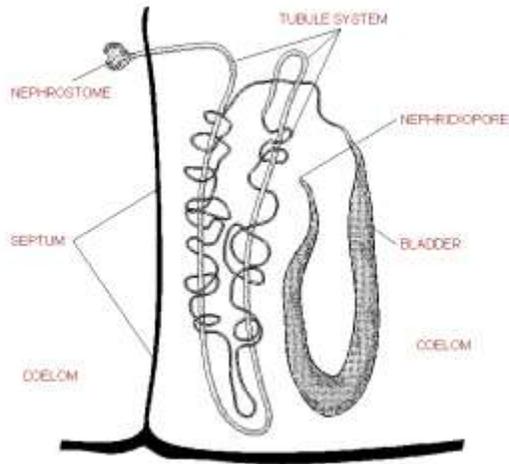
#### i) Modification of body surface

The organism try to make up their body surface impermeable to water. So that the problem of water entering into the body is minimized. Arthropoda have calcified exoskeleton, Fishes have scale, & even in annelids i.e. in Nereids etc. exoskeleton is hardened. If hard exoskeleton is absent the animals secrete mucus around the body so that osmotic regulation problem is minimized.



In spite of this water can enter into the bodies of these organisms through flexible joints or thin walled joints or respiratory surfaces. This water has to be regulated & when it is excreted some required salts may be lost. To avoid this the organisms have developed specialised tissue Nephridia. In unicellular organisms contractile vacuole helps in regulation. In higher animals i.e. platyhelminthes – flame cells have connection to the exterior through which they give out excretory fluid. It prevents salt loss.

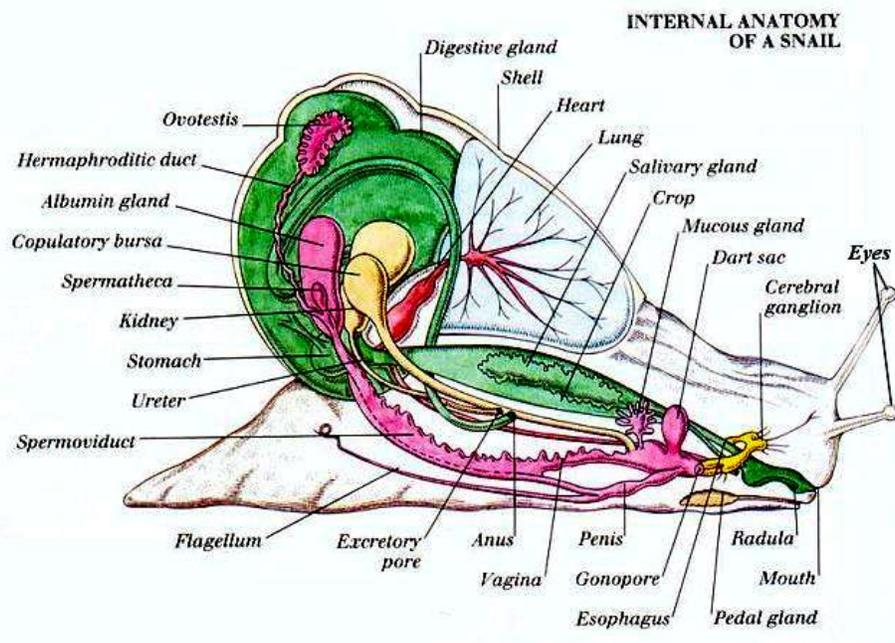


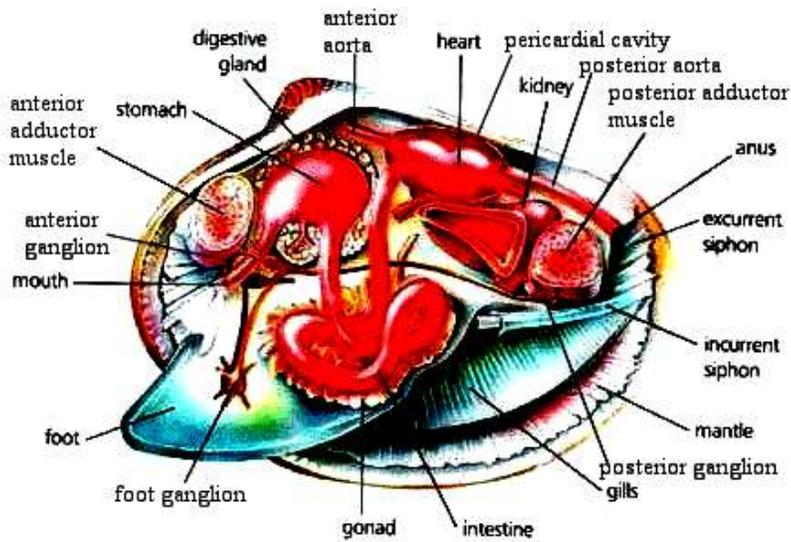


In annelids there are metanephridia.

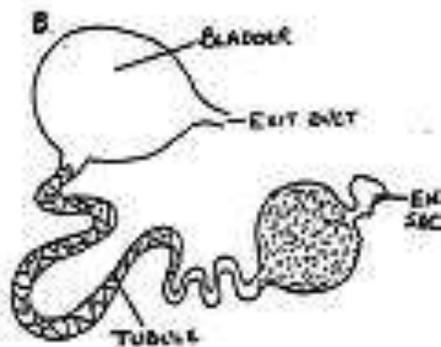
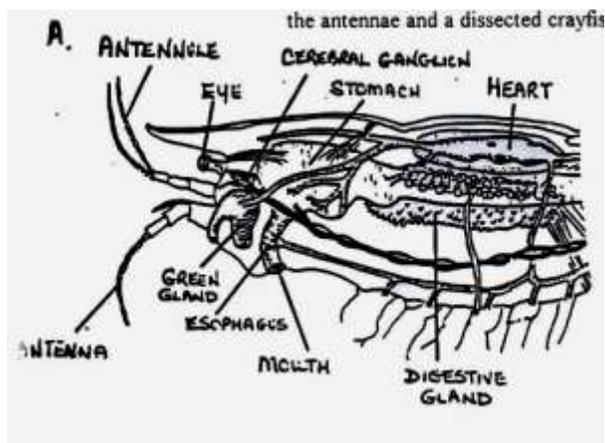
Metanephridium is a reabsorption type of kidney. In this coelomic fluid enters through the funnel into the nephridium from which essential salts are reabsorbed & the urine produced is given out.

From mollusca onwards we have nephridia arranged in complex manner. In this kidney urine is produced by filtration. Hence protein loss is prevented. From the urine formed, required salts are reabsorbed & unwanted excretory materials are secreted in urine by specialised cell. Hence molluscan kidney is known as filtration & reabsorption & secretion type of kidney





In higher organism like crustacean have a green gland that act as a kidney. It is ultrafiltration, reabsorption & secretion type of kidney.



Even the higher organism have ultrafiltration, reabsorption & secretion type of kidney.

All different types of kidney play important role in excretion of water & at the same time achieve conservation of useful salts & elimination of harmful substances.

Inspite of this the kidneys are not able to expel distilled water & hence some salts are lost. To make up loss normally the marine animals have to consumes food with salt & along with that the marine water is ingested. When marine water is ingested it has high Na & other salts so the animals get excess dose of salt than required & to tackle them different organisms have specialized tissues to eliminate excessive salts ions.

- i) In lower invertebrates normally general body surface acts as ionic regulation surface i.e. it can absorb or eliminate the salts as per required.
- ii) In fish we find the cells of gills act as salt regulatory surface. Whereas in case elasmobranchs salt gland is present associated with rectum. It opens into cloaca.



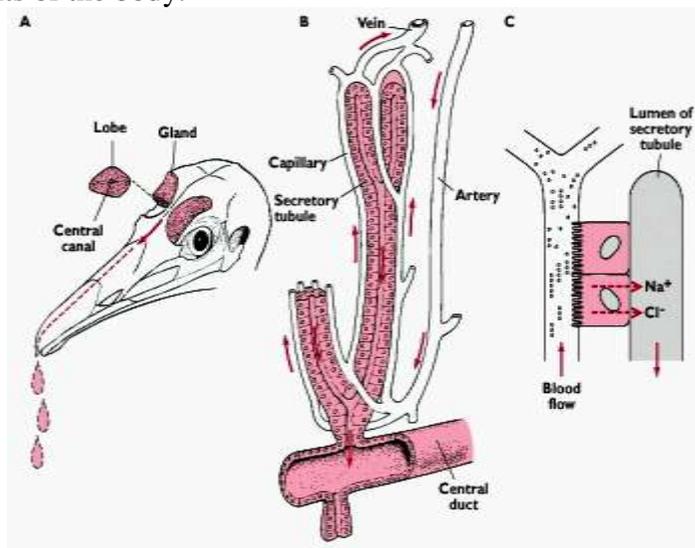


In case of turtle specialised salts glands are present which open in orbit of eye & that is why often it is said that the “**turtle cry salty tears.**”

In Iguana specialised salt glands are present. They open in nostrils & hence it is said that the “**Iguana sneeze out excessive salt.**”

In sea snakes salt glands open in mouth.

In case of marine birds salt glands open in nasal passage. Thus we say that with different specialised tissue the organisms can manage the ionic and osmotic contents of the body.



With ontogeny i.e. with development from young to adult the tissues handling cause change.

Ex. In Herring fish experiment was done & it was found that the egg in fresh water swell, in high saline water shrink & are resistant to ionic & osmotic pressure. But when the larva comes out, general body surface regulates water & salt. In embryo gastula the ectoderm regulates water & salt. In adult, gills & kidney start regulating water & salt.

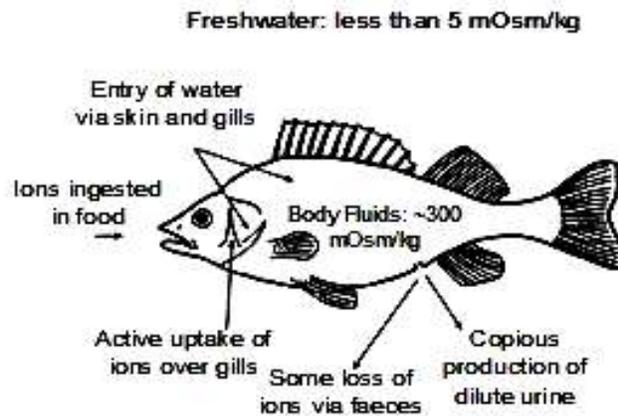
Apart from this they are helped by hormones & among hormones prolactin & Adrenal play vital role. Prolactin affects Gills, Kidney & skin. Adrenal hormones in marine fishes affects the gills & guts. It helps in absorption through gut & elimination through gills.

### Organisms living in hypo-osmotic environment

- They include fresh water organisms,
- All Estuarine organisms
- They also include migratory organisms.

The problems faced by the organism -

- 1) Water enters the body & the cells & the body will swell. (Water gain)
- 2) Salts are leached out from the body (Salt loss)

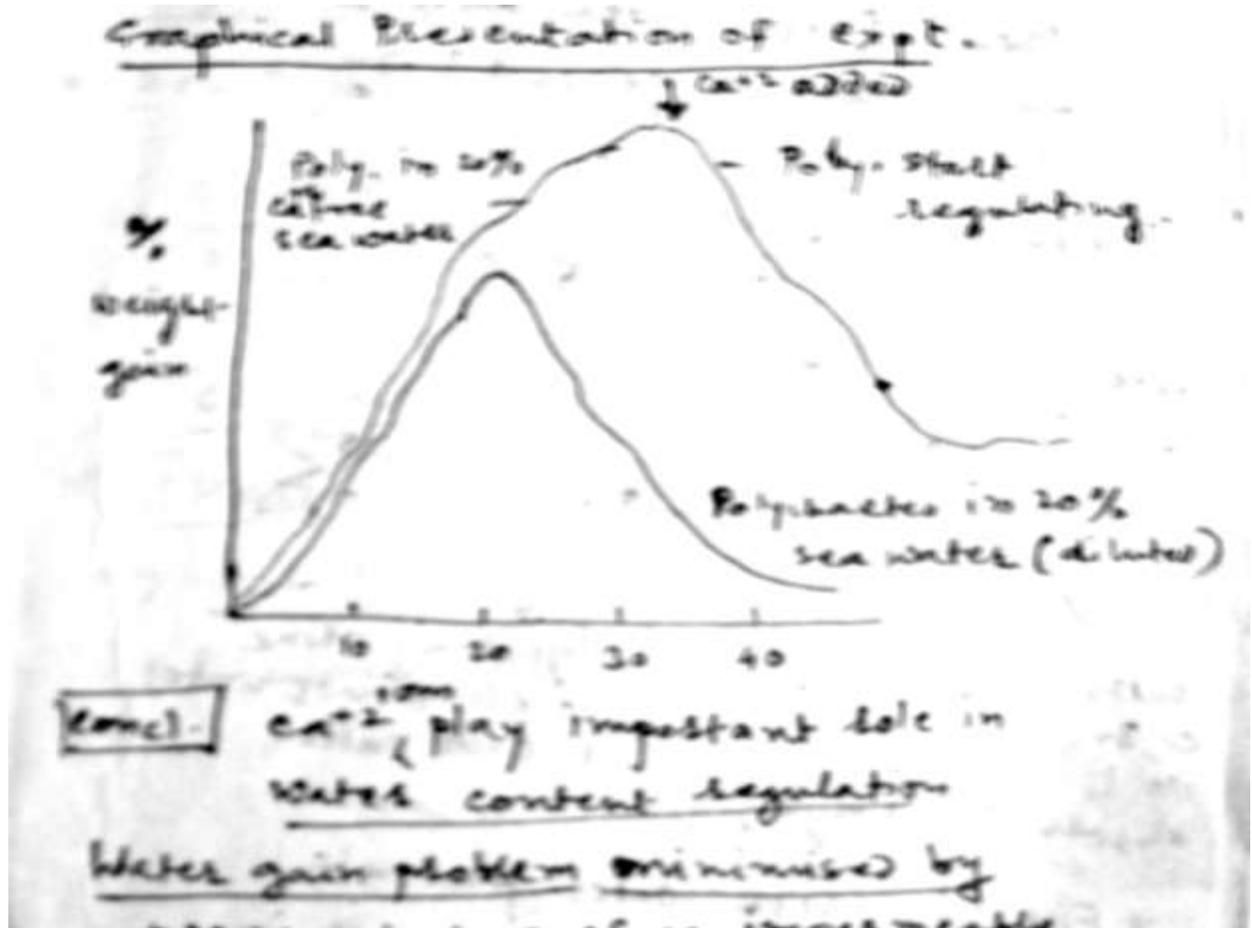


Proof



- Polychaet *Nereis diversicolor* was studied, the polychaete was kept in dilute marine water or fresh water. It gained weight for some hours due to water gain, but afterwards regained normal body weight by controlling water contents.

- When the polychaete was kept in calcium free dilute sea water ,it went on gaining water and swelled too much . But when calcium was added to the medium, the polychaete started regulation of water.
- Thus water regulation depends on availability of calcium.



Conclusion – Calcium ions proved important in water regulation.

Again an experiment was done on Nereis & the polychaete was kept in sucrose solution isoosmotic to seawater. It was found that they lost weight due to loss of salt. This proves that in hypoosmotic condition the organism face two problems

- i) salt loss from body
- ii) water gain by the body

To overcome this the organism make there body surface impermeable to water / ions by calcification / chitinization etc. or secretion of mucus on body.

Inspite of this the water gain is through flexible 'thin walled' joint, & respiration surface & when there is gain of water then the osmotic regulation should be done. When water is eliminated salts are lost.

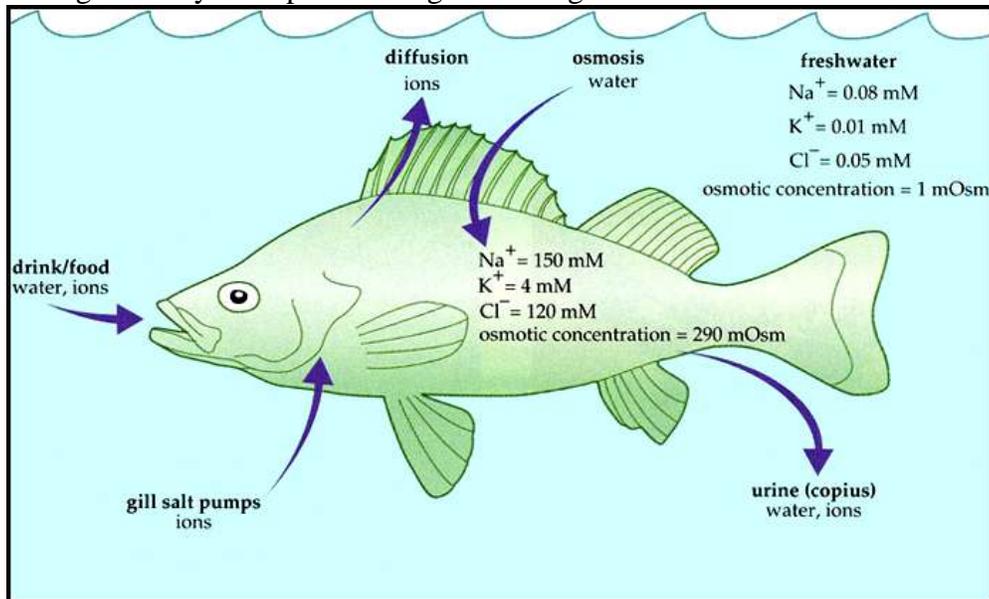
To prevent salt loss the kidneys are modified. For example Eriocheir (Crab) is Euryhaline. It can live in Marine as well as fresh water. When in fresh water it produces urine isosmotic to body fluids to keep the salt loss minimum. Even then there is loss of salt. To overcome this it shows absorption of salt through epithelial cells of the gills.



Prawns (Euryhaline) when in fresh water absorb salts through general body surface.

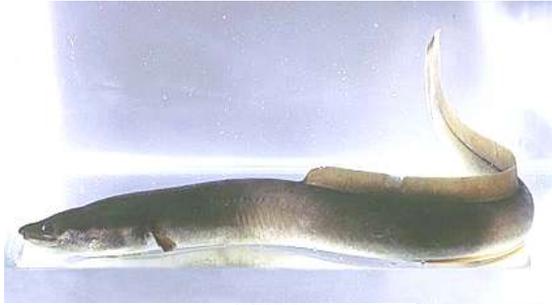


Fish : try to minimise salt by producing dilute urine. But still whatever salt is lost, is regulated by absorption through cells of the gills.



In Eel Anguilla

When in fresh water Gills absorb salts but in marine water gills excrete salts.



In Amphibia. Hypotonic urine is produced but at the same time they absorb salts through general body surface. The adjustment of osmotic & ionic regulation is brought about by the hormones & most of the hormones are diuretic. These hormones produce dilute urine or hypotonic urine.

In case of Earthworm the diuretic hormone is secreted by brain cells. In Pulmonate snails – green cells of pleural ganglion secrete diuretic hormone. In case of higher animals pituitary secretes the diuretic hormone. This hormone has favourable effect on gills, salt gland & general body surface.

Fish Fundulus when kept in dilute sea water or in fresh water can survive. But if the pituitary is removed it can not survive in fresh water. But in such fish, if the pituitary extract is injected it survives. Thus the prolactin secreted by pituitary plays an important role in ionic & osmotic regulation.



Stickle back lives in fresh water during summer & in marine water during winter & when it is in fresh water in prolactin secretion rises.

Adrenal cortex hormones are also important for fresh water living or marine water living. In marine water it causes excretion of salts through gills / excretory surfaces. In fresh water living there is absorption of salt as and when required.

### **Hyperosmotic living**

Ionic & osmotic problems of hyperosmotic living

Organisms in hyperosmotic environment are few like marine lamprey, teleost fishes, grapsid crabs (Polygrapsus & Hemigrapsus), palaemonid prawns, coelacanth fish (Latimeria). Their body fluid is dilute than sea water & therefore there are living is hyperosmotic. Some organisms live in evaporating water of salt pans. for example Artemia (Brine shrimp) breeds in crystalline water. Aedes mosquito larvae (breeding in seawater)

- Artemia



- Hemigrapsus



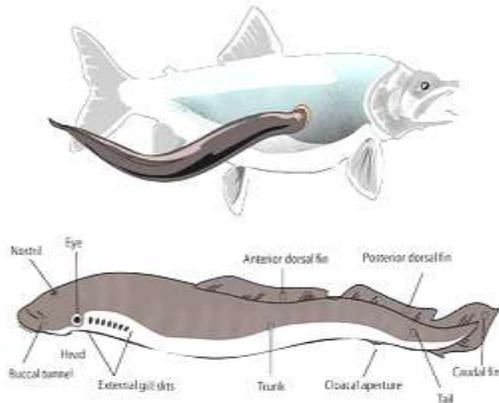
- Latimeria



- Grapsid crab



- marine lamprey

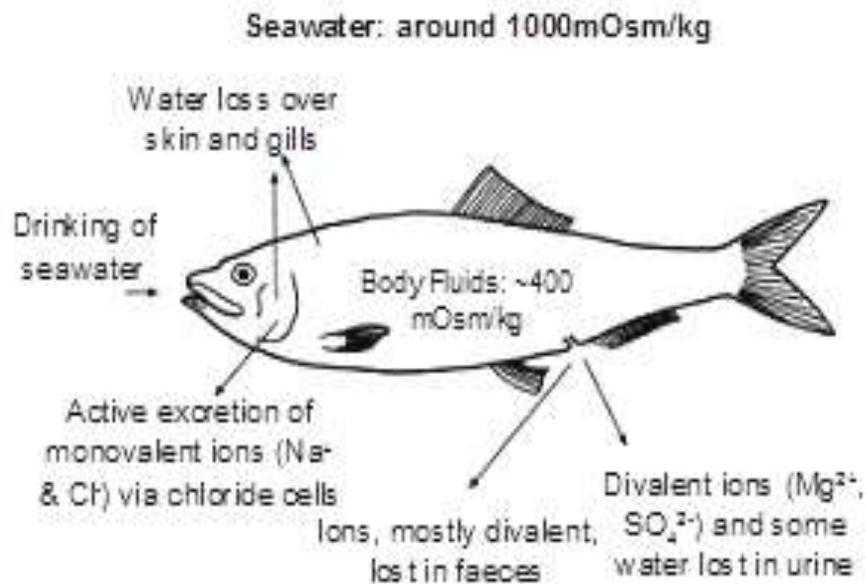


palaemonid prawns



#### Problems arising

- 1) water loss from body
- 2) salt gain



Water loss is so severe that they have to drink water very often. Eel when in fresh water don't drink water but when in marine water it drinks salty water to overcome water loss which leads to the addition of salts in the body resulting in excess of salt in the body.



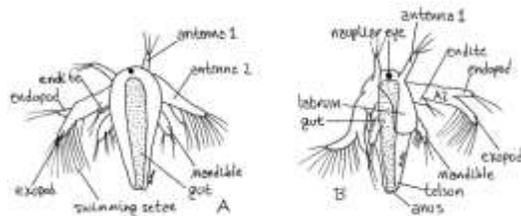
In eels excessive salts are eliminated by acidophilic cells of gills.  
 In case of cyclostomata & fishes when salt water is ingested it creates another problem. Water absorption in the intestine becomes difficult due to salty contents of the lumen. To overcome this problem salts are actively absorbed in anterior oesophagus and then water is absorbed in the intestine. The excessive absorbed are excreted through gills. Apart from this specialized salts excreting glands help in elimination of salts.

It has been shown that in Eel when in fresh water oesophagus is permeable to water & salt. In marine water oesophagus impermeable to water & absorb only salt so that marine water gets diluted & water absorption is possible in rectum. The organisms in hyperosmotic environment try to reduce water loss by reducing the quantity of urine produced. For this purpose they show modification in their kidney where the less amount of urine is produced. For example in some animals the no. of glomeruli is less or in some glomeruli are present but there neck is constricted so that there is no ultrafiltration.

While in some fishes like Toad fish (Opsanus) glomeruli are altogether absent. It is always found the kidneys are well modified. Kidneys eliminate monovalent ions while gills eliminate  $\text{SO}_4^-$  or  $\text{Mg}^{++}$ .



courtesy U.S Geological Survey



In *Artemia salina* is a Euryhaine animal, it can live in glass distilled water or crystallizing marine water. In crystallizing marine water it drinks salty water & excess NaCl is excreted through gills or branchial glands. In these glands it is seen that the Cl is given out actively & Na is given out passively. Salt excretion is

very rapid. In larval *Artemia* branchial gland is absent. In them neck gland & cephalothorax does the excretory function.

*Aedes* larvae – In marine water they drink excess salt water & eliminate salts by producing salty excreta. For this purpose their posterior part of rectum secretes unwanted salts in excreta. (When in fresh water anterior rectum absorbs salts.) These larvae also have anal papillae which help in ionic & water regulation.



The organisms in hyperosmotic living have one more mechanism to minimize ionic and osmotic problems. They accumulate metabolites so as to maintain the body fluid concentration similar to concentration of water in which they live.

In some organism trimethylamine oxide – TMAO & NPS – ninhydrin positive substance like Taurin & glycoxilic acid stored in tissue so as to make tissue isoosmotic & prevent salt loss.

Specially molluscs show accumulation of NPS. It is also shown by green toad (*Bufo viridis*) which also accumulates urea & salts in its body.



The cartilaginous fishes like shark accumulate urea in their bodies to make their body fluid isosmotic to the environment.

### **Add on hormones and pumps**

#### **Ionic Pumps and hormones**

During ionic regulation organism need active transport of ions either inward or outward. For which there are various pumps available such Na, K, Cl, Mg, Ca. Na pump is most studied. Whenever  $\text{Na}^+$  accumulates inside tissue &  $\text{K}^+$  outside tissue it stimulates  $\text{Na}^+$  pump. It activates enzyme of ATPase & energy is used for elimination of  $\text{Na}^+$ . Oxygen consumption is also increases. In absence of  $\text{Mg}^{++}$  Na-pump can not work. Normally in this pump  $\text{Na}^+$  is exchanged with  $\text{K}^+$  or  $\text{H}^+$  or  $\text{NH}_4^+$ .  $\text{Cl}^-$  is exchanged with  $\text{HCO}_3^-$ .

Like Na-pump, Cl-pump is studied in frog .

K-pump is studied in Cercapia. It is also studied the  $\text{Ca}^{++}$  is important in ionic & osmotic regulation for permeability of membrane.

Hormones play important role in regulation of different pumps

Prolactin affects the cells of Gills , Skin, Kidney and prevents salt loss in fresh water.

Thyroid hormone decrease actively in hypoosmotic regulation & rises actively in hyperosmotic regulation.

#### **Adrenal hormone**

Aldosterone increases Na absorption & water retention. Renin is important for regulation of  $\text{Ca}^{++}$  in blood.

Thus there are different hormones & pumps at tissue level to regulation ions & water.

### **Problems of terrestrial living**

→ Water loss is main problem.

→ Along with water loss salt (ionic) loss is also seen.

Water loss is from i) Integumentary water loss

ii) Respiratory surface water loss

iii) Urinary water loss

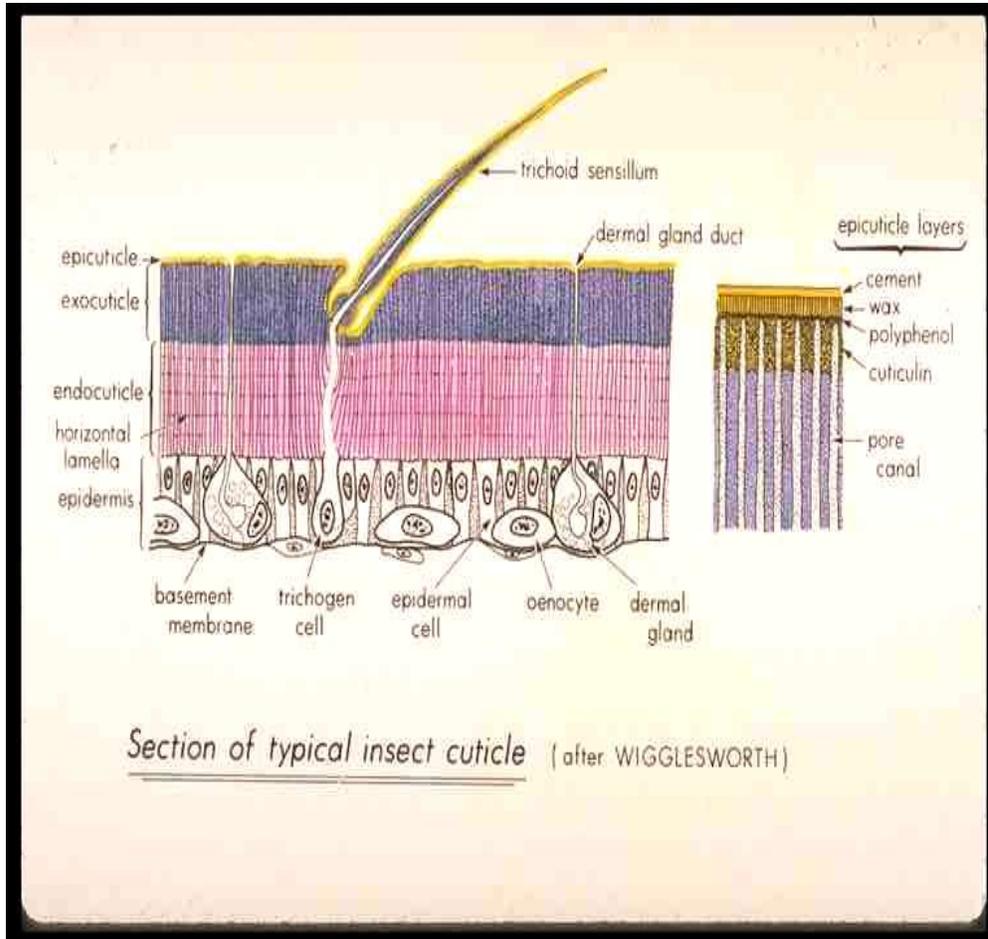
#### **Prevention of integumentary water loss**

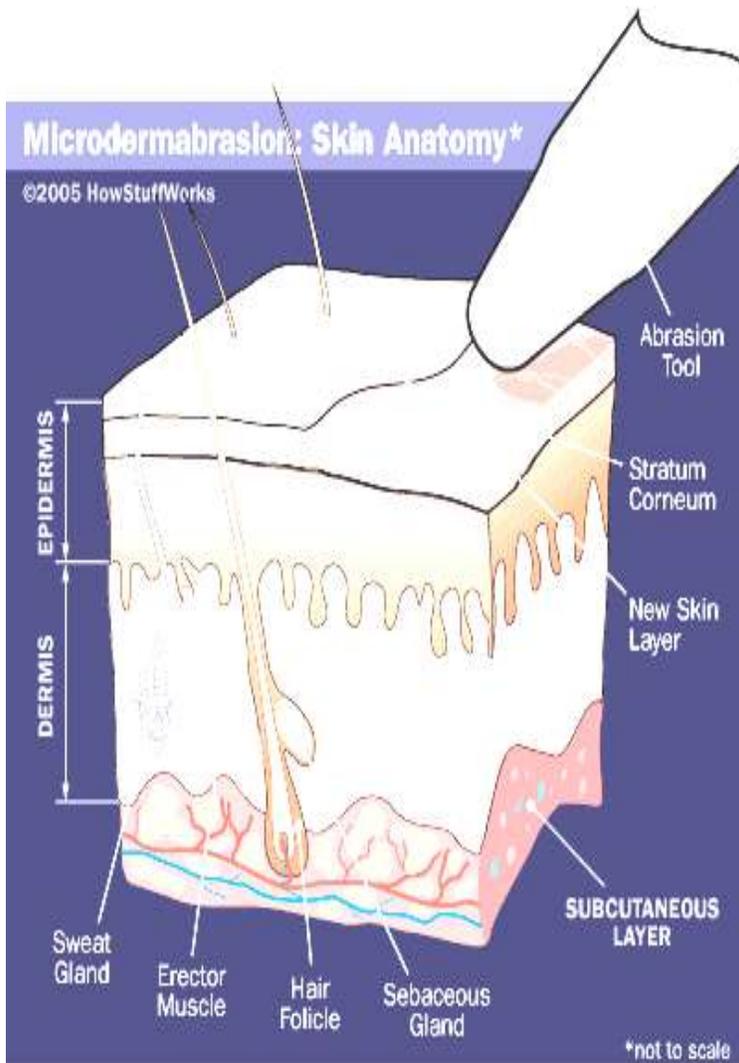
→ Animals make their integument impermeable to water

◆ Arthropods use chitin & calcium

◆ Insects have chitinous integument + Waxy layer on body due to this evaporation is prevented.to a great extent.

- ◆ In vertebrates there is a layer stratum corneum which is keratinized epithelium to prevent water loss. (In Amphibian the stratum corneum is absent. So they depend much on water.





### Prevention of Respiratory surface water loss

- Insects have cyclical respiration. In cockroaches the spiracles remain closed for a long time & remain open for a short time. During open phase large amount of  $\text{CO}_2$  is given out.
- In birds, mammals & reptiles the nasal mucosa is moist due to which vapour is condensed & water going out is minimized.
- In some desert animals like Kangaroo rats the nasal passage is longer and moist to prevent water loss.



Thus the animals try to prevent respiratory surface water loss.

### Prevention of Urinary water loss

- For this mainly kidneys have to be modified
- Kidneys in amphibians, mammals & reptiles have less no. of glomeruli. This causes low filtration & less urine formation.
- Mammals have loop of Henle in which ions & water is reabsorbed. It facilitates more absorption of water whenever needed.
- In amphibians & turtles water from urine is absorbed in urinary bladder.
- Birds, crocodiles, lizards urine is given out in cloaca. It is passed in the rectum where water is reabsorbed.

For further prevention all these organisms are equipped with hormones hormones like antidiuretic hormone (ADH) and diuretic hormones (DH).

- They are secreted in earthworm by brain cells.
- In snails secreted by green cells of pleural ganglion or yellow cells.
- In insects secreted by Thoracic ganglion.
- In Rhodnius bug, when fully fed, crop is full of blood. Due to this pressure is developed on thoracic ganglion, it secretes diuretic hormones & excess of water is removed.



- Desert mammals need more hormone for regulation & pituitary is larger in size,

Apart from this the animals are equipped with some additional phenomena. - like absorption of water from surrounding e.g.

- Insects have vesicles associated with rectum which absorbs water vapour or moisture from air. These vesicles are pencil like.
- Amphibians absorb water from surrounding through their skin.
- Some animals have ability to efficiently use metabolic water
- Especially in desert mammal the metabolic water generated
- Ex. Kangaroo rat don't consume water at all. Fat rich food products are consumed more to regulate metabolic rate.

### Ionic Regulation

Normally ions are lost through urine. The terrestrial animals try to minimize ion loss through different ways. The ions are also restored through the salts in the food.

For this the animals show different behaviors.

Ex. Herbivores animals consume grass which is raw and does not contain much salts. Therefore animals like deer show salt licking phenomenon to regulate ions. The salt levels in the body affect preferences of the animals. e.g. Rats that are given salt free diet prefer to drink salty water rather than normal water.

#### **Hormonal regulation of salts :**

Different hormones in different organisms play important role in regulation of salts.

- ◆ In Pulmonate snails green cells of pleural ganglion & Yellow cells of parietal ganglion secrete hormones for ionic balance.
- ◆ In corpora cardiaca in insects secretes chloride Transport stimulating hormone (TSH) that stimulates cyclic AMP production in rectal cells & activates the chloride pump for regulation. This hormone also has effect on cells of Malpighian tubules.

#### **Hormones of higher organism**

- ◆ In vertebrates pituitary & adrenal gland hormones are important in ionic regulation.
- ◆ These hormones in birds affect salt glands & cause ionic regulation
- ◆ In mammals they affect the kidney, intestine, skin mammary glands & amniotic membrane.

Adreno cortico steroid (Aldosteron) secreted by adrenal cortex is responsible for ionic regulation

If adrenal cortex is removed it causes loss of Na, Cl & water & retention of potassium. Thus aldosteron governs absorption of Na, Cl & water & excretion of 'K'.

It not only affects kidney but also sweat glands, salivary glands & intestine. It is present in amphibian, reptiles, birds & mammals.

Apart from this adrenaline, thyroid hormones & also insulin have effect on ionic or electrolyte regulation.

- **Renin – Angiotensin system** is highly evolved in mammalian kidney & it regulates Na, Cl & blood pressure etc.

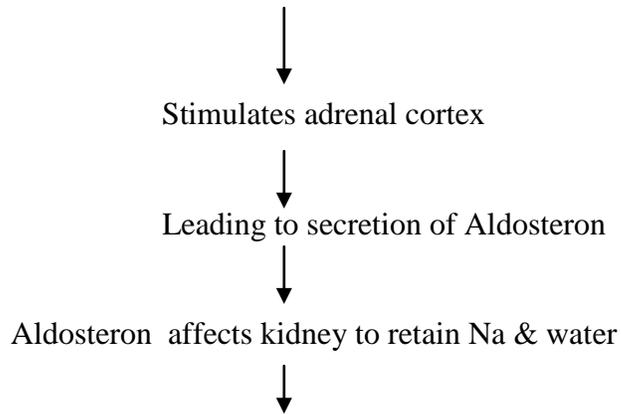
In mammals kidney there is Juxta glomerular apparatus (JG apparatus) which is made up of two components

- i) Juxta glomerular cells present in afferent glomerular artery.
- ii) Macula Densa cells in distal convoluted tubules. These together form JG apparatus.

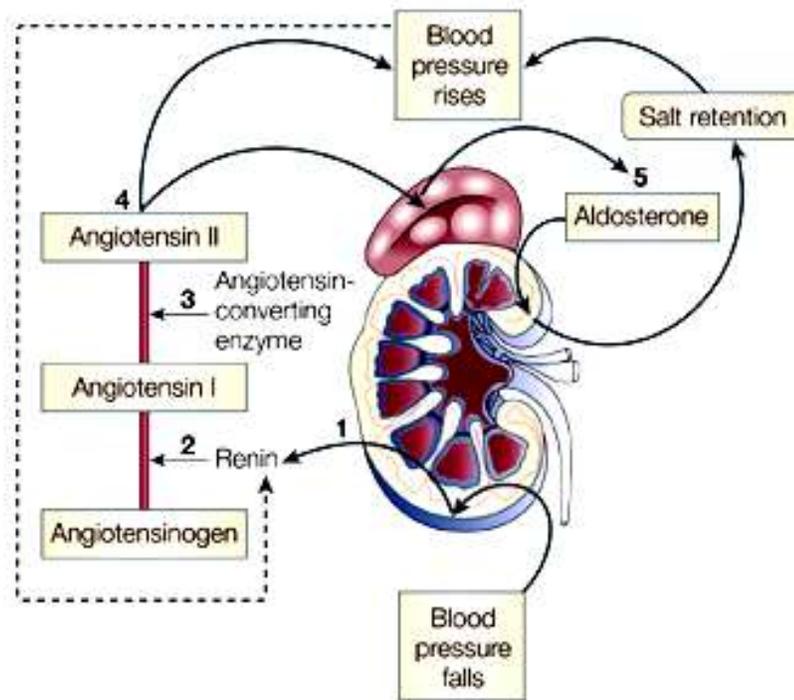
This apparatus is sensitive to low B.P., low Na & Cl in blood, low extra cellular fluid or non-epinephrine/ nor-adrenaline & whenever influenced by these it is stimulated & produces an enzyme Renin. This enzyme acts on Angiotensinogen in plasma and converts it to Angiotensin I which is converted to Angiotensin II .

It causes vasoconstriction to rise B.P

Angiotensin II also secretes nor-epinephrine



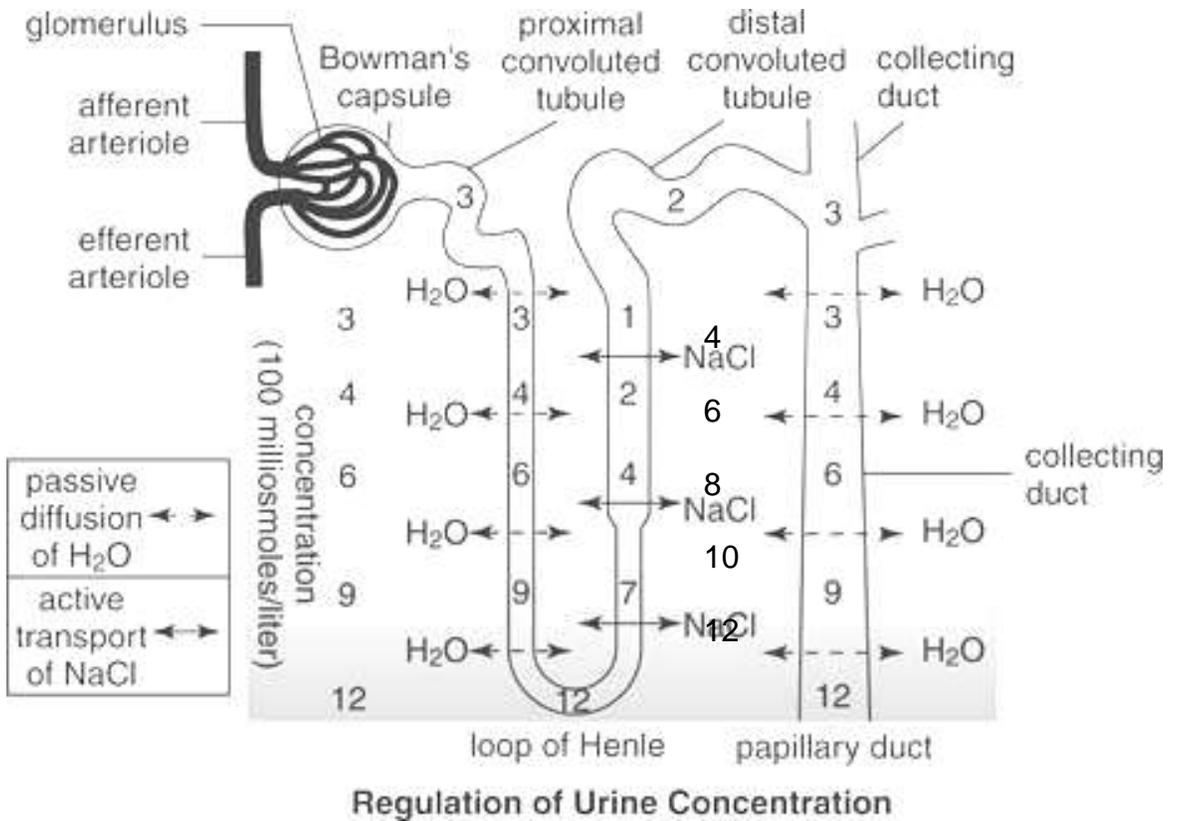
The net result is rise in B.P., rise in Na & water. This change leads to feed back inhibition of the JG apparatus to stop the reaction chain.



**Counter current multiplier system**

We know very well that in mammals there is hair pin loop i.e. loop of Henley which is used re absorption of urine & water. 180 l urine is formed by ultra filtration in a day but actually only 1.5 l urine is finally excreted. This is due to re absorption in the loop of Henley

In loop of Henley there is counter current multiplier system due to which Na, Ca, K & Mg and water are reabsorbed.



As shown in the diagram in the descending limb water goes out passively and Na enters in causing built up of salt concentration. The ascending limb is impermeable to water & pump out Na to build a concentration gradient of salt on both sides( In interstitial fluid ). Due to this gradient when urine comes down in collecting tubule it meets with a salt gradient of higher concentration. Walls of collecting duct are permeable to water. So water gets reabsorbed thus minimizing water loss.

In this system urine follows in counter current manner i.e. downward → upward → downward & higher concentration gradient is formed or multiple concentration gradient is formed. Hence the system is known as counter current multiplier system.