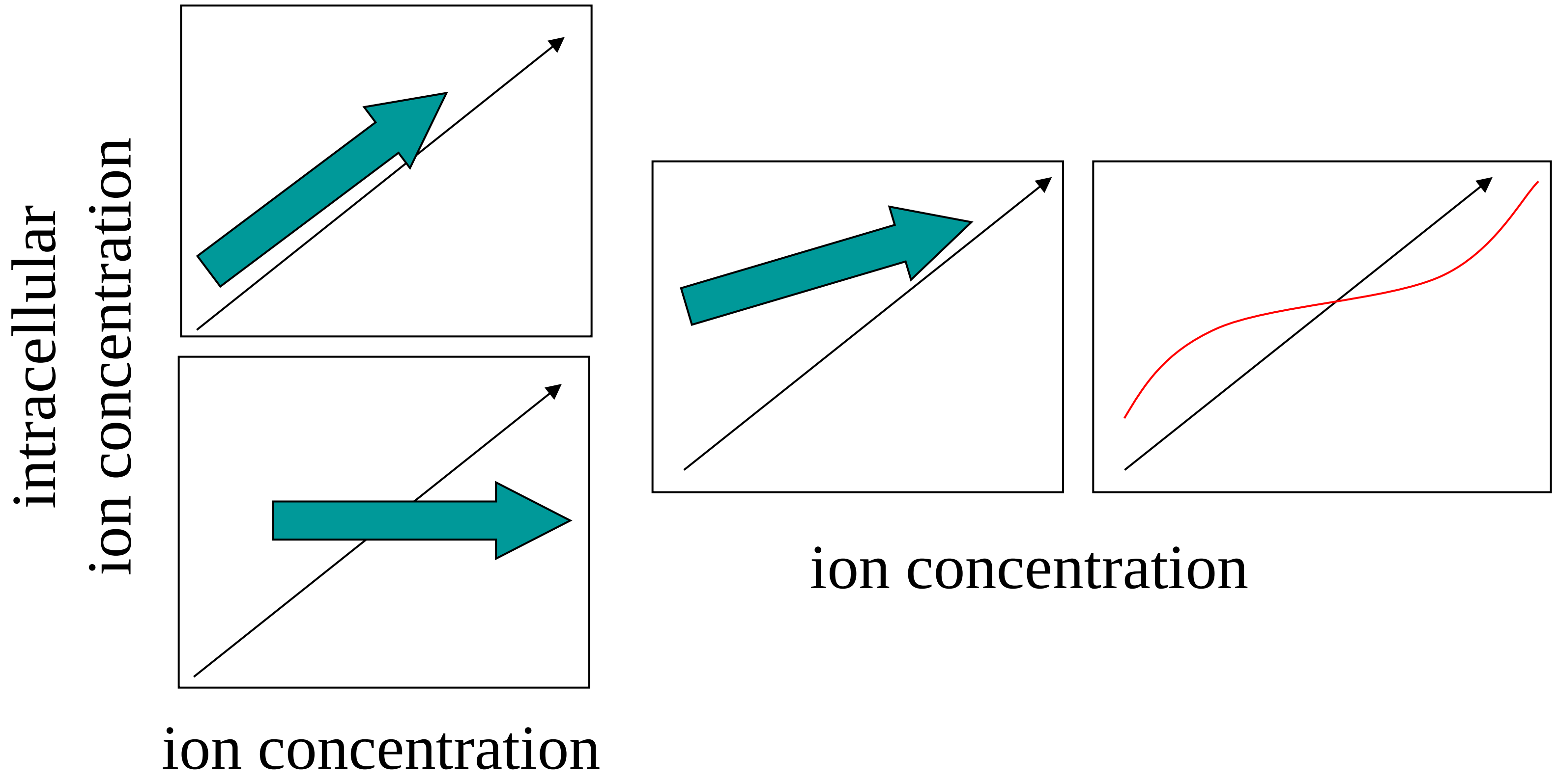
Ion balance and osmoregulation

Different ionic concentrations than their environment (ionoregulators)

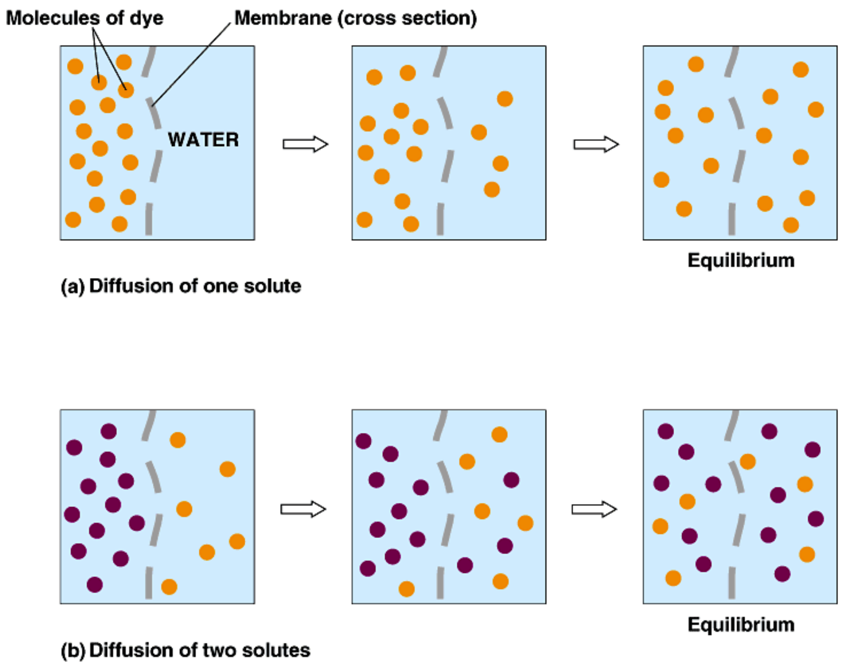
Highly permeable membranes (ions and water), specially gills, gut, skin.

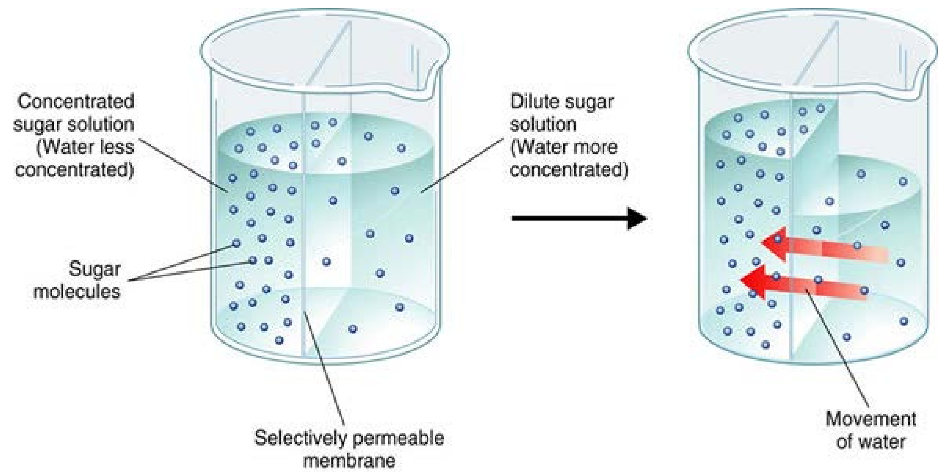
Control mechanisms: none (osmoconformers) ion balance (osmoregulators)

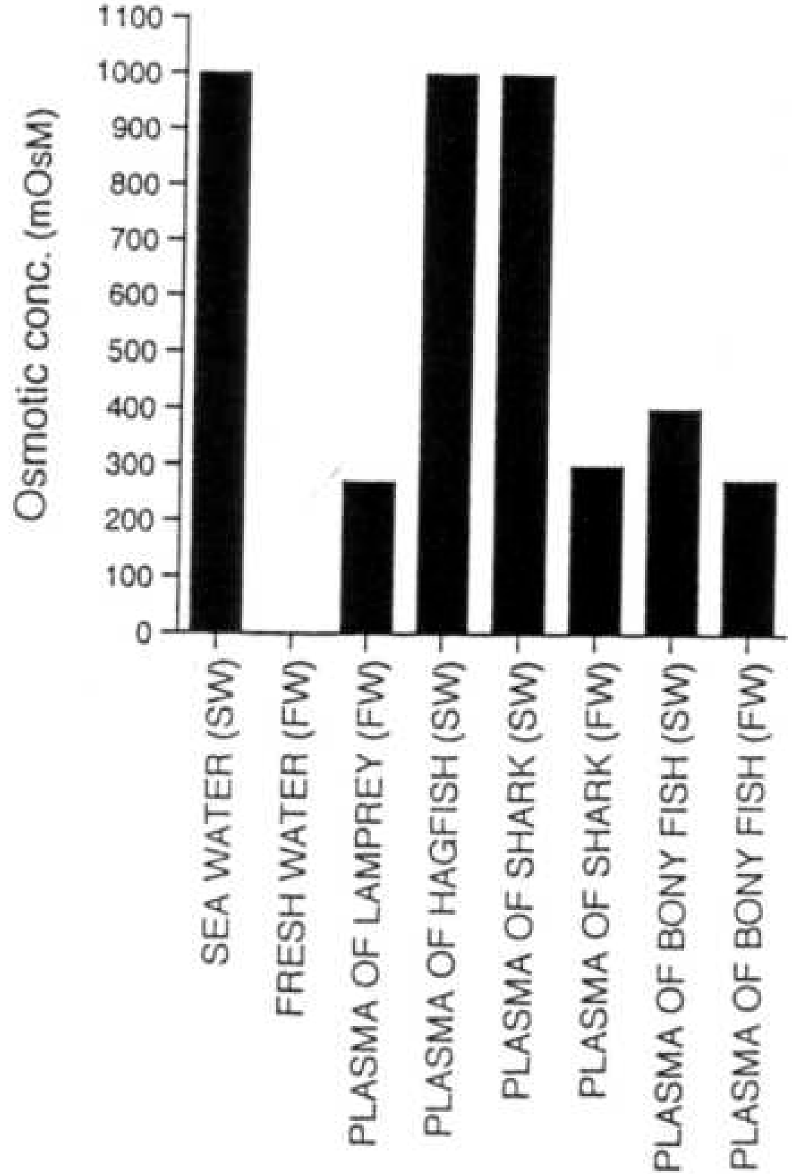


Most invertebrates are osmoconformers, some are quasi-conformers while other are osmoregulators. Most vertebrates are osmoregulators.

Diffusion and Osmosis






Osmotic conc. (mOsM)
1100
1000
900
800
700
600
500
400
300
200
100
0
SEA WATER (SW)
FRESH WATER (FW)
PLASMA OF LAMPREY (FW)
PLASMA OF HAGFISH (SW)
PLASMA OF SHARK (SW)
PLASMA OF SHARK (FW)
PLASMA OF BONY FISH (SW)
PLASMA OF BONY FISH (FW)

Freshwater bony fish
Hypertonic [Body] > [Environment]
= Ion loss
= Water influx

Kidney = Efficient monovalent ion resorption (low water permeability)

Urination every 20 - 30 minutes!

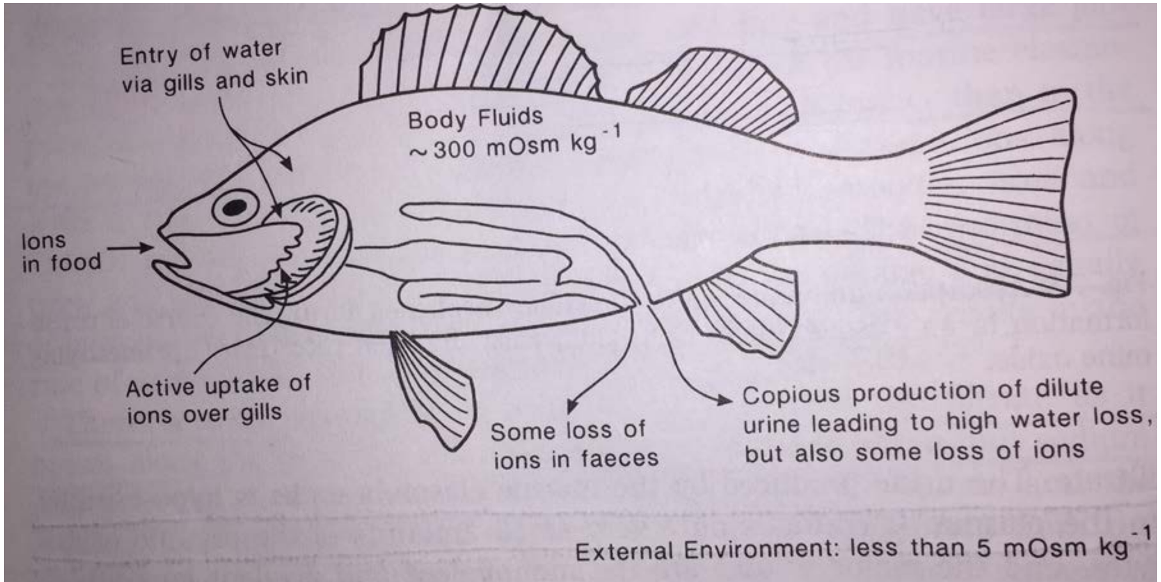


Fig. 7.10 Summary of ionic exchange and osmoregulation in a freshwater teleost.

Saltwater bony fish
Hypotonic [Body] < [Environment]
= Water loss
= Ion influx (due to drinking)

Small amount of concentrated urine
1 - 2% of body weight/day

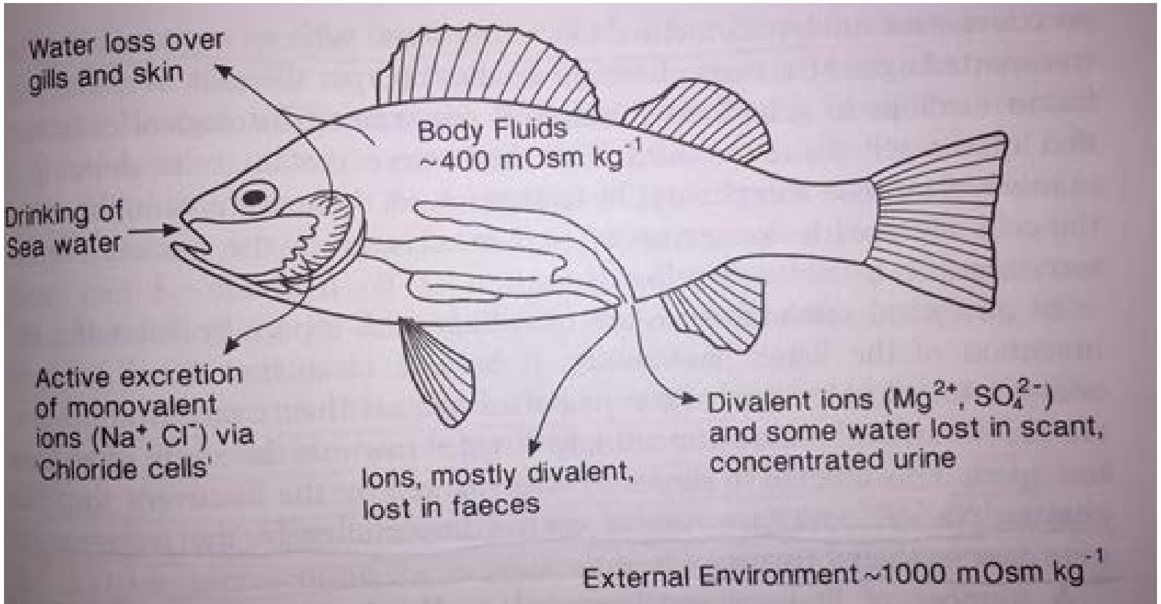


Fig. 7.2 Summary of ionic exchanges and osmoregulation in a marine teleost.

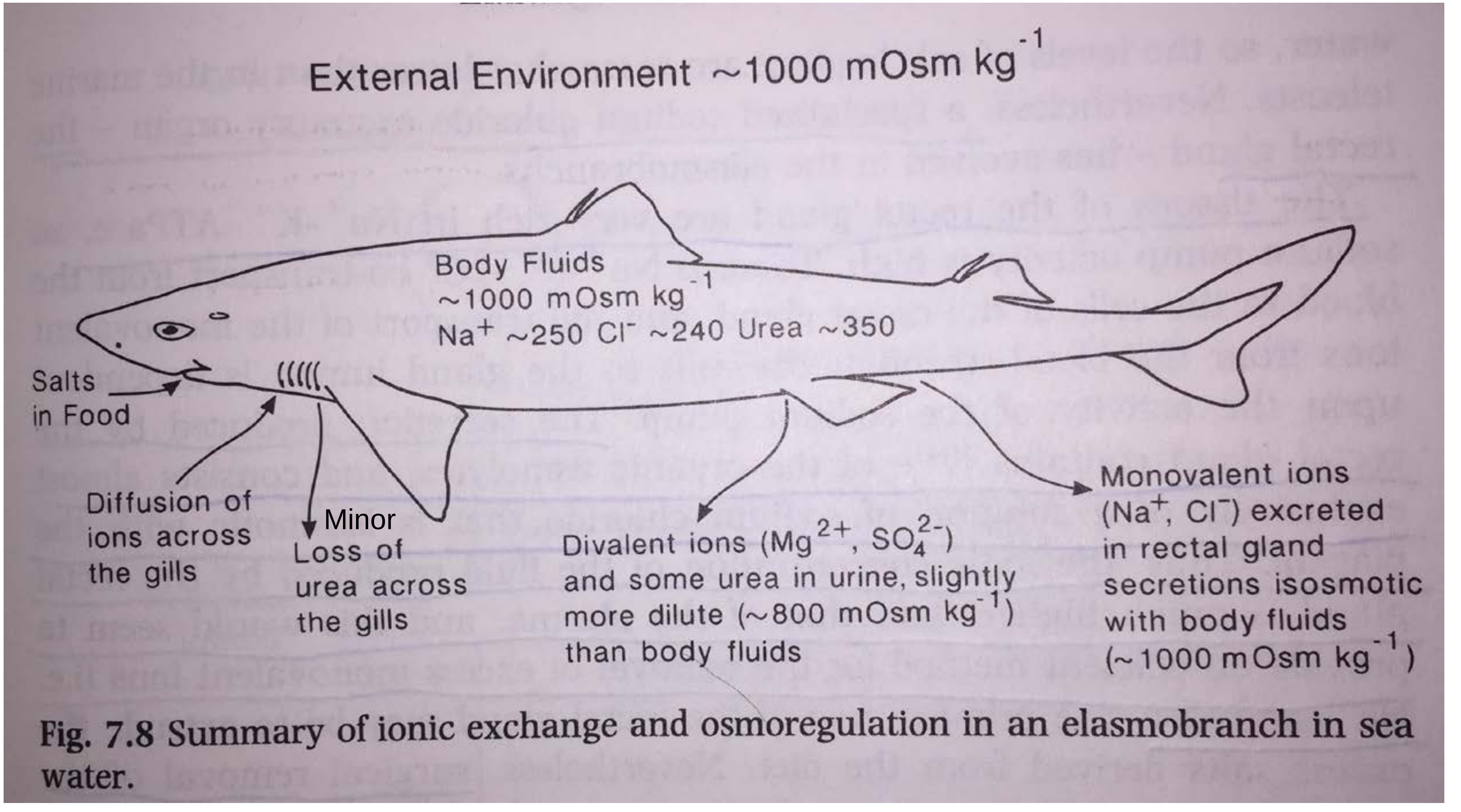
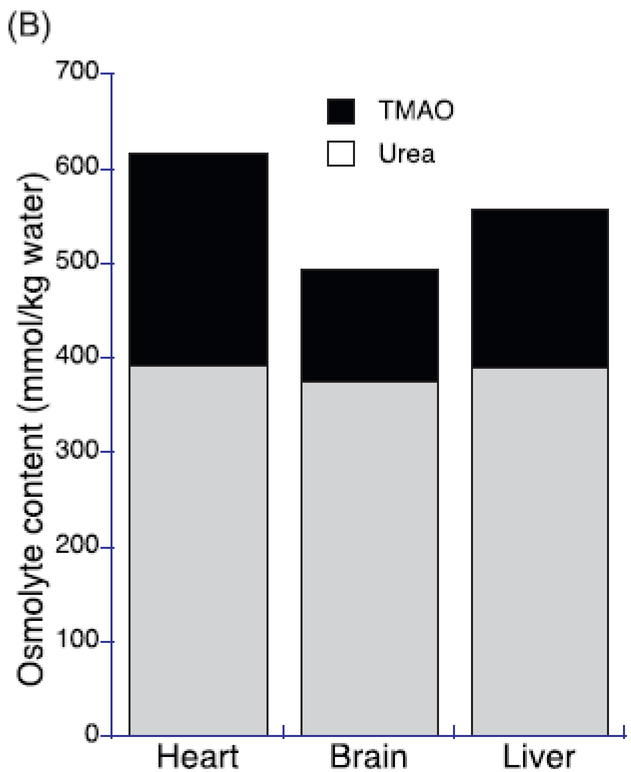


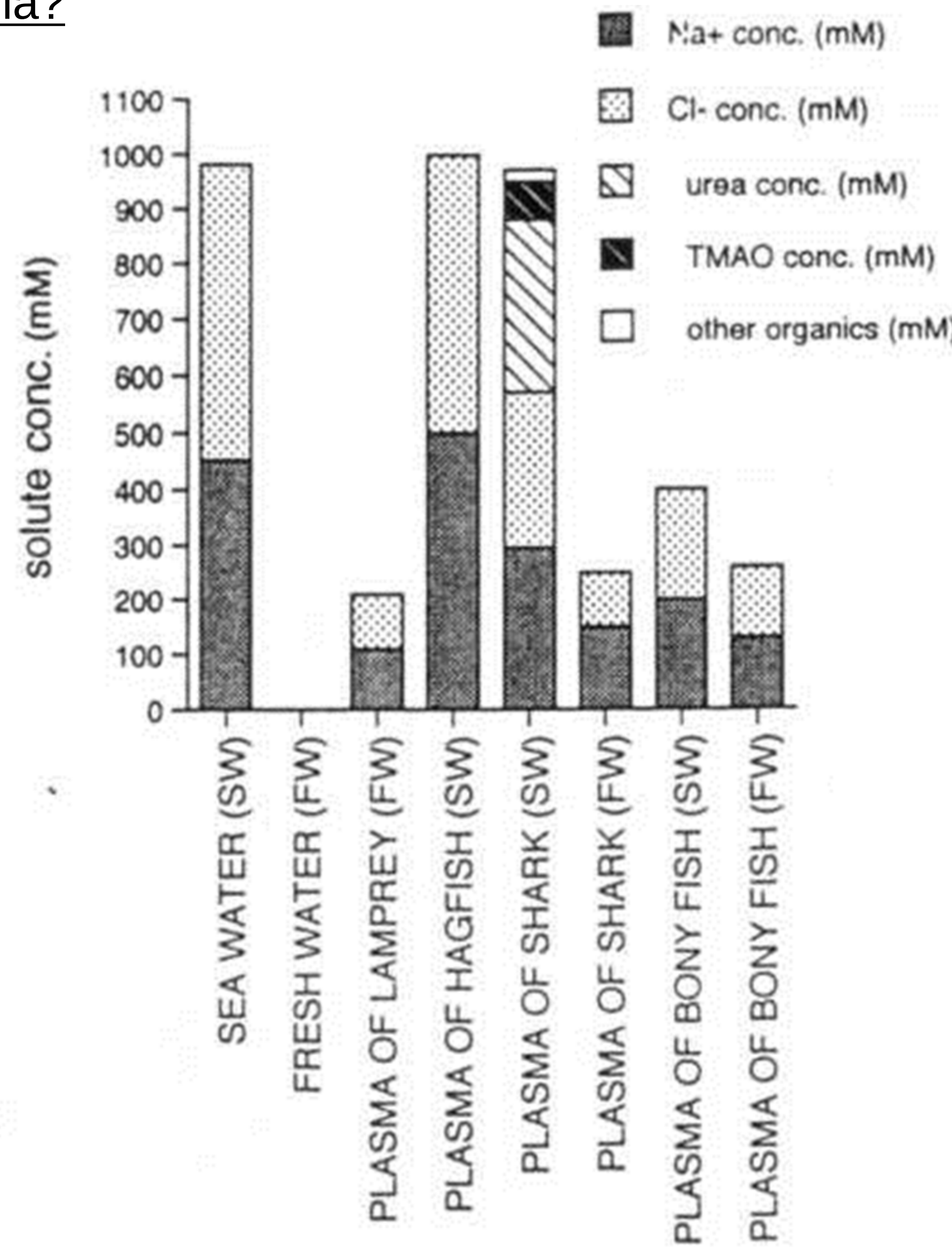
Fig. 7.8 Summary of ionic exchange and osmoregulation in an elasmobranch in sea water.

Saltwater elasmobranch
Isosmotic (slightly hypertonic) [Body] ≥ [Environment]
= Neutral water movement (some drinking does occur @ 10% rate of SW teleost)
= Influx of ions (body hypo-ionic); ions make up 50-60% of osmolality

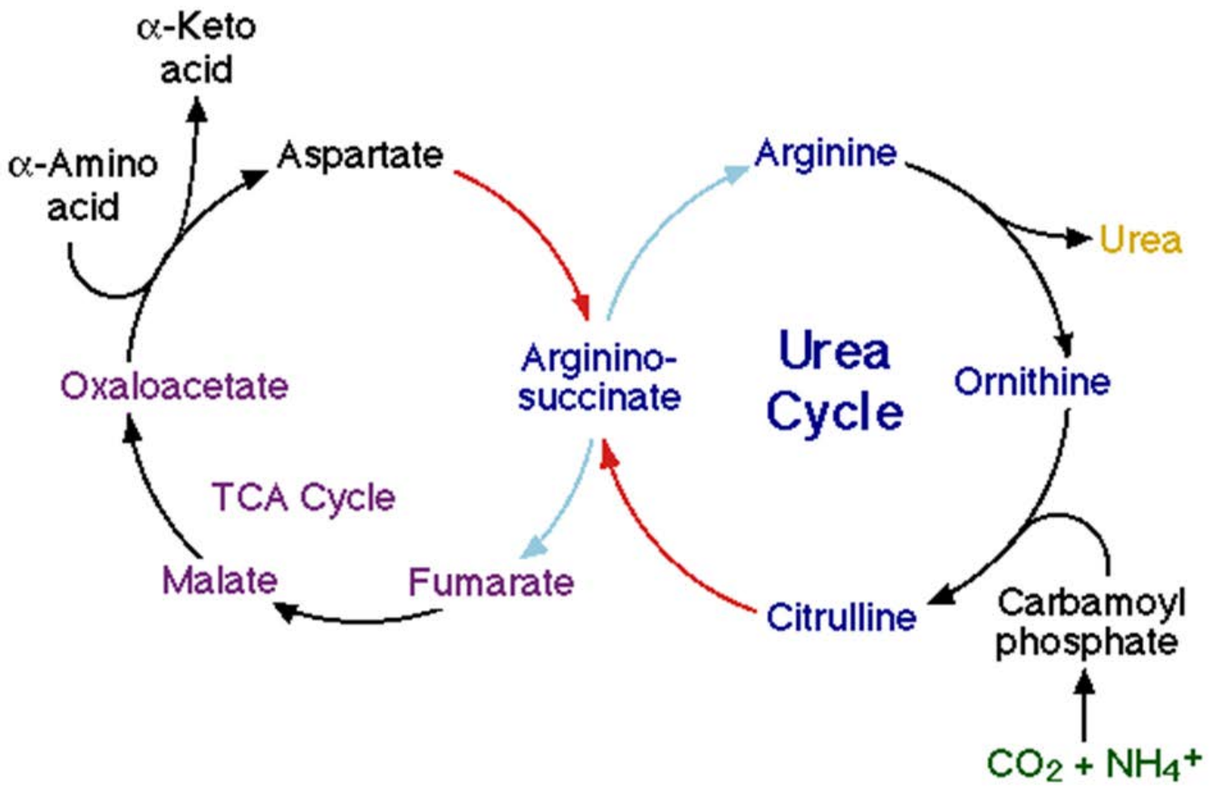
Osmotic balance made up by urea (toxic!!) ~350 - 500 mOsm (30 – 50%)
Urea toxicity counteracted by trimethylamine oxide (TMAO) (5 – 10%)

TMAO:Urea = 1:2 (TMAO = 50% of osmotic strength = ~175 – 200 mOsm)
Intracellular [TMAO] = 5X greater than extracellular [TMAO]
Source of TMAO = diet? Mitochondria?





Urea production - Ornithine-Urea Cycle (OUC)

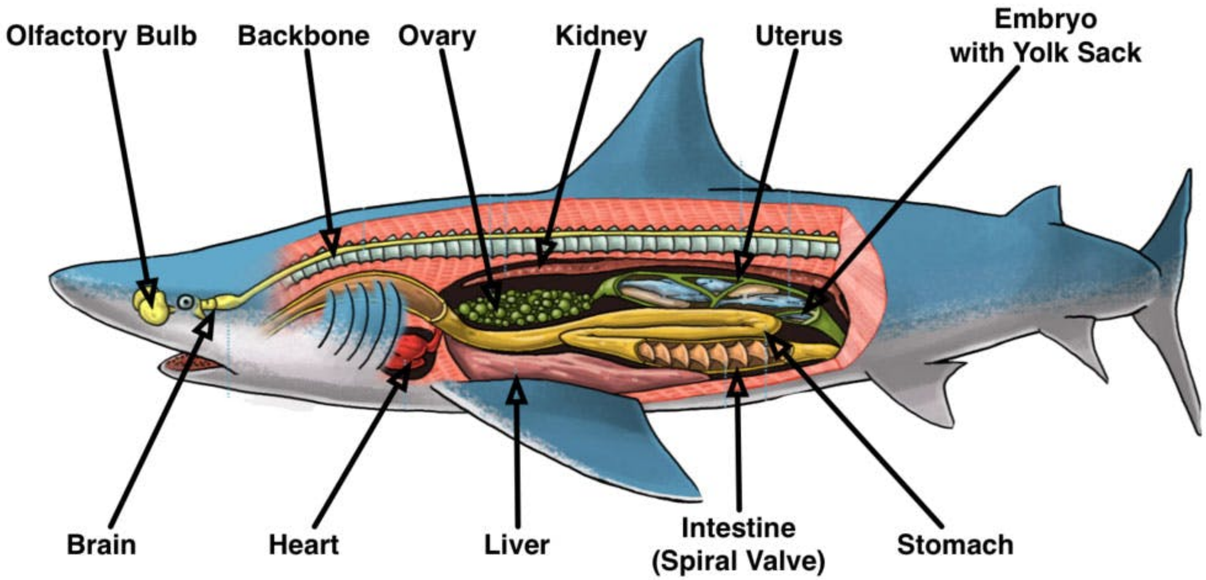


Primarily produced in liver, specifically in mitochondria (some production in muscle)
<u>Metabolically expensive to produce urea: 5 ATP/mole of urea; ~10% of O2 consumption</u>
<u>NEED TO MINIMIZE LOSS</u>
Toxic in most vertebrates = chondrichthyans evolved proteins and enzymes that aren't denatured by high [urea]

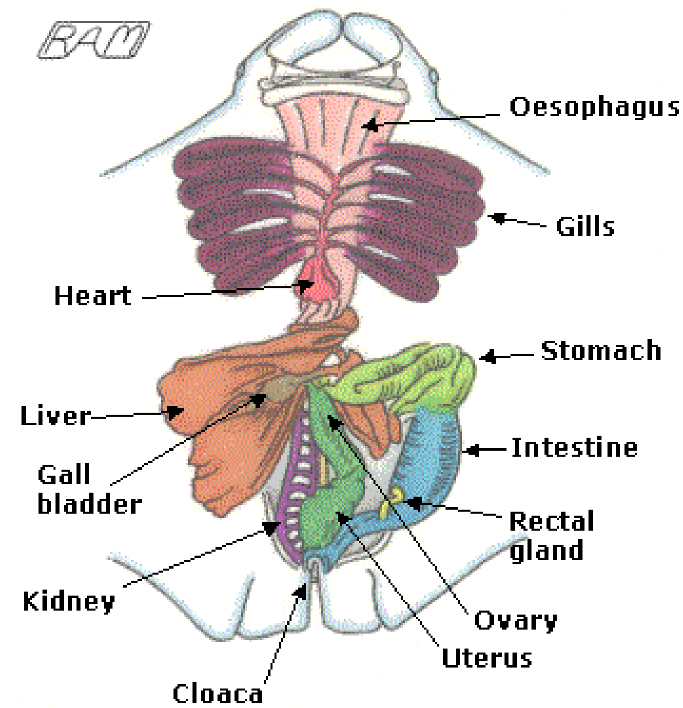
Urea/NH3 excretion

Species	Environment osmolality	Ammonia excretion (μmol $N \cdot kg^{-1} \cdot h^{-1}$)	Urea excretion (μmol $N \cdot kg^{-1} \cdot h^{-1}$)	Ratio ammonia: urea rates
Marine				
Taeniura lymma	30 ppt	120	740	0.16
Hemiscyllium plagiosum	33 ppt	110	1336	0.08
Leucoraja erinacea	33 ppt	140	400	0.35
	100% SW	111	480	0.23
Squalus acanthias	30 ppt	21	570	0.04
	30 ppt	28	549	0.05
	Fasted	60	750	0.08
	Fed (10 h)	112	1020	0.11
Raja rhina	30 ppt	145	1620	0.09

Kidney



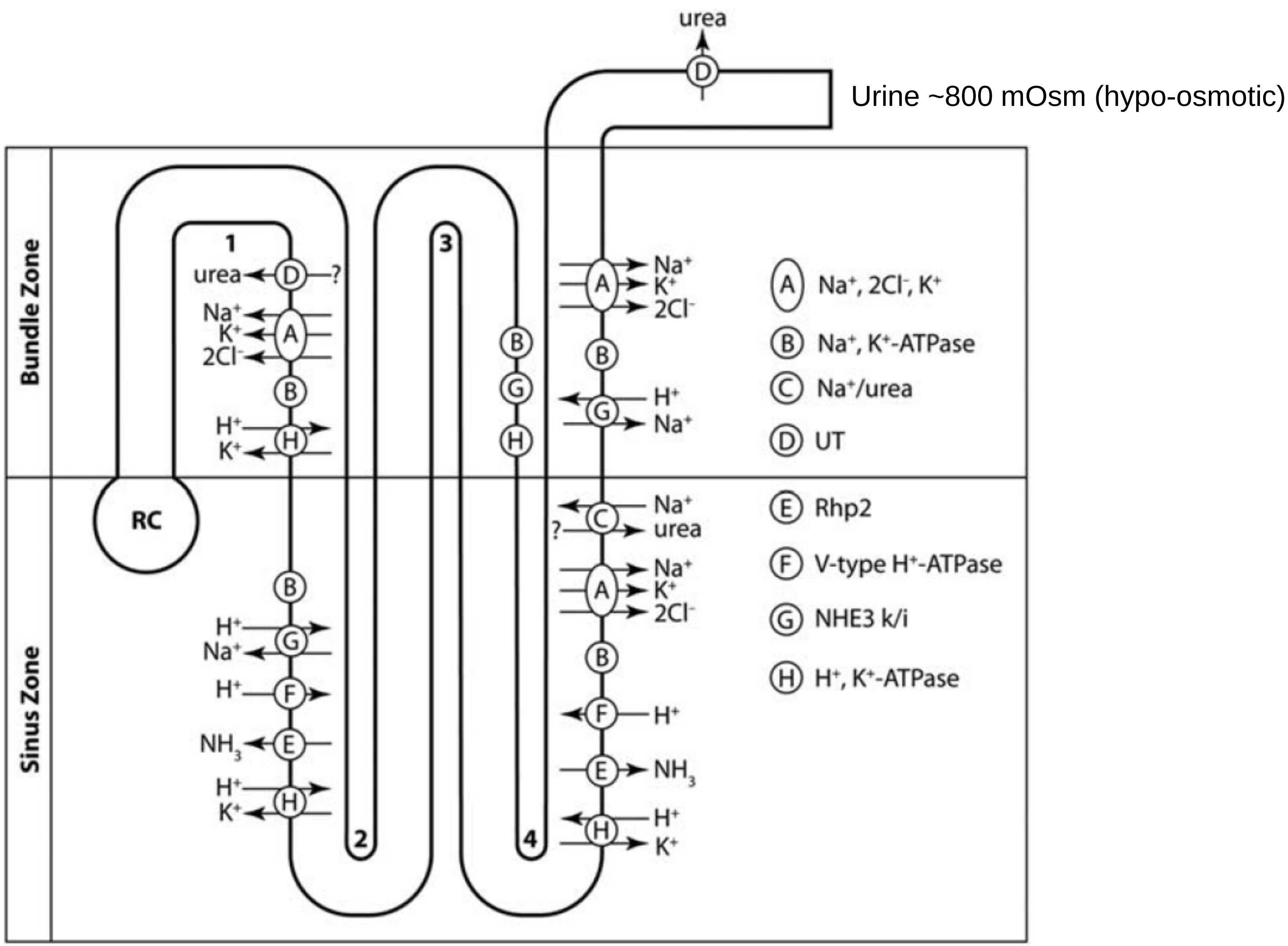
Olfactory Bulb
Backbone
Ovary
Kidney
Uterus
Embryo with Yolk Sack
Brain
Heart
Liver
Intestine (Spiral Valve)
Stomach



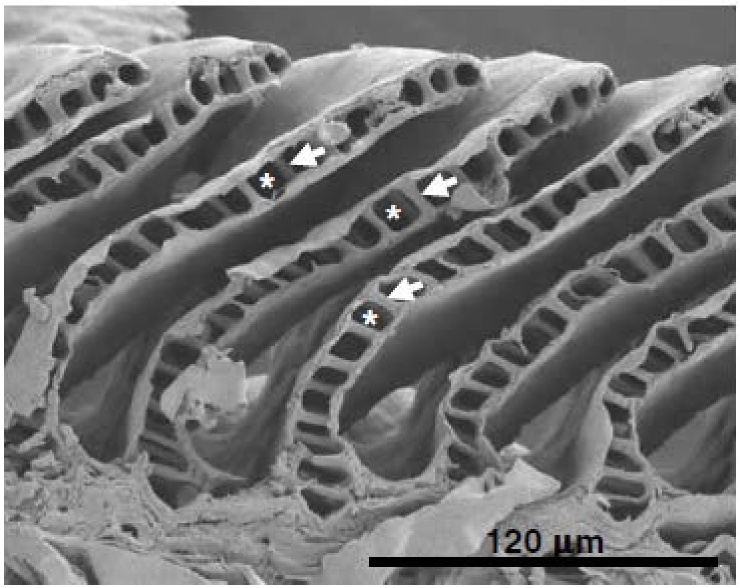
Oesophagus
Gills
Heart
Stomach
Liver
Intestine
Gall bladder
Rectal gland
Kidney
Ovary
Uterus
Cloaca

Urea re-absorption/retention and ion exchange: kidney

- Very efficient (90-96% re-absorption of urea)
- Active transport and counter-current system
- Mostly divalent ions (Mg^{+2}, $SO4^{-2}$) excreted in urine
- Monovalent ions (Na^{+}, Cl^{-}) resorbed (some excreted)

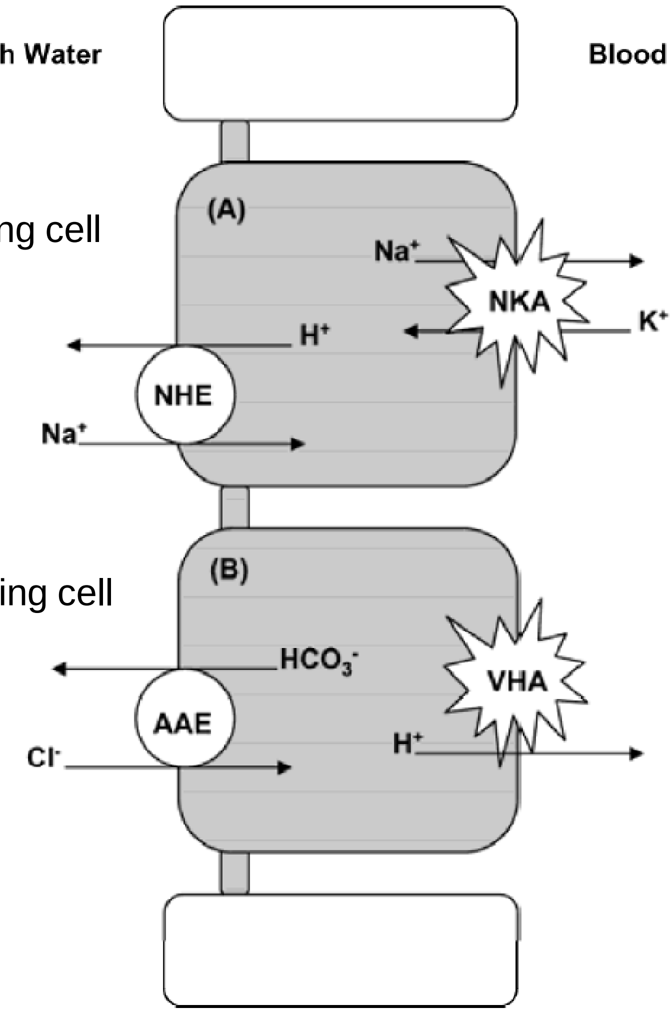


Elasmobranch Gills



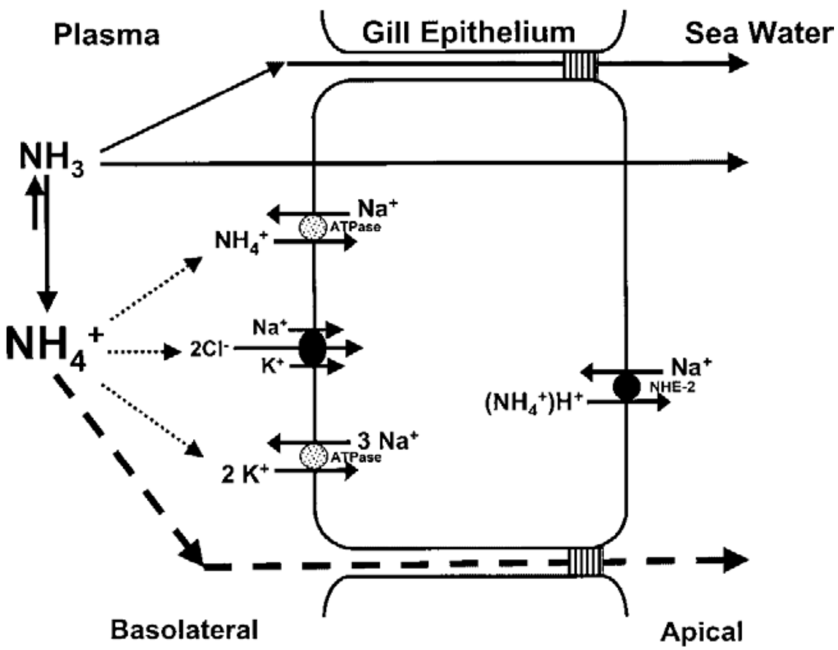
Acid secreting cell

Base secreting cell

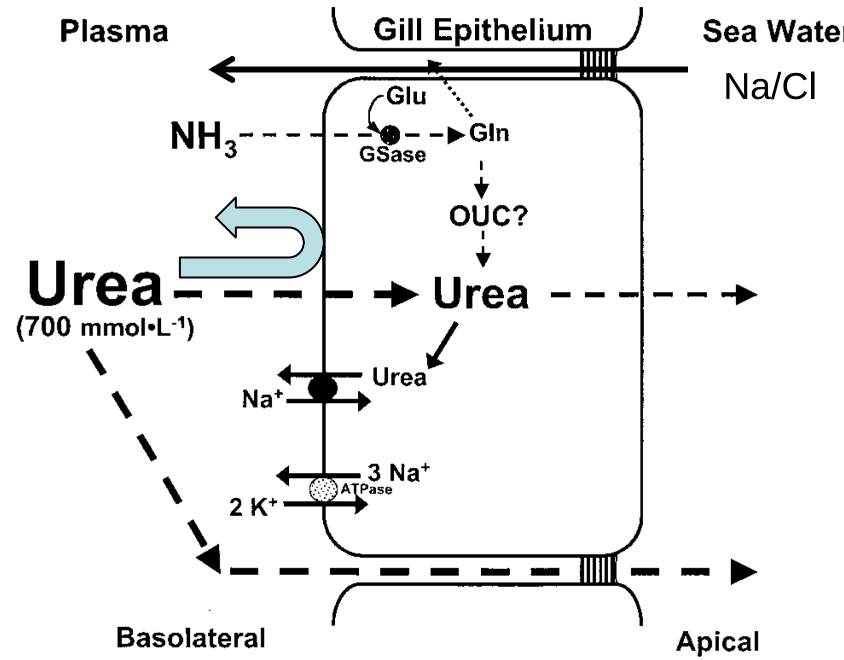


Urea retention and ion exchange in the gills

Saltwater teleost



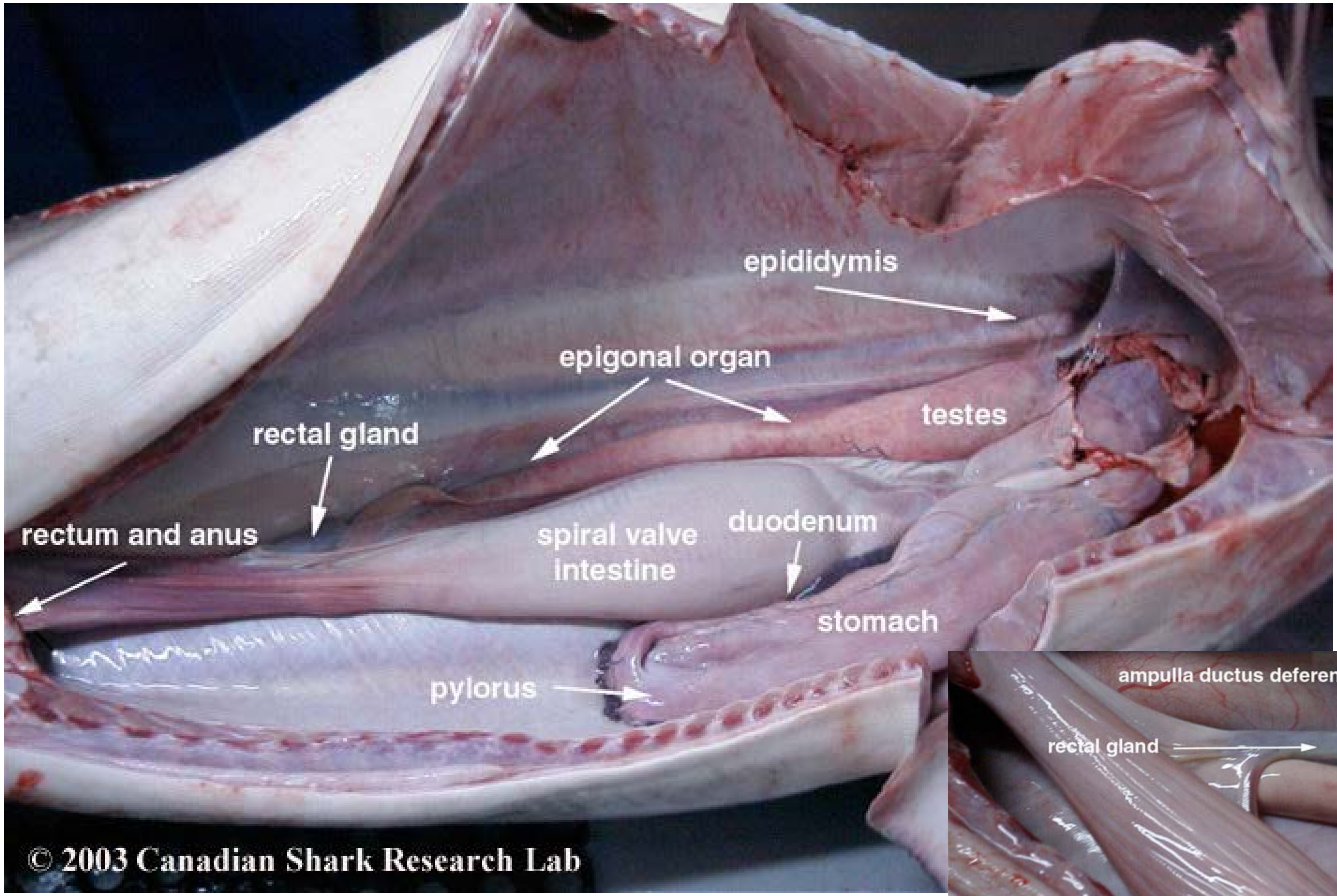
Elasmobranch

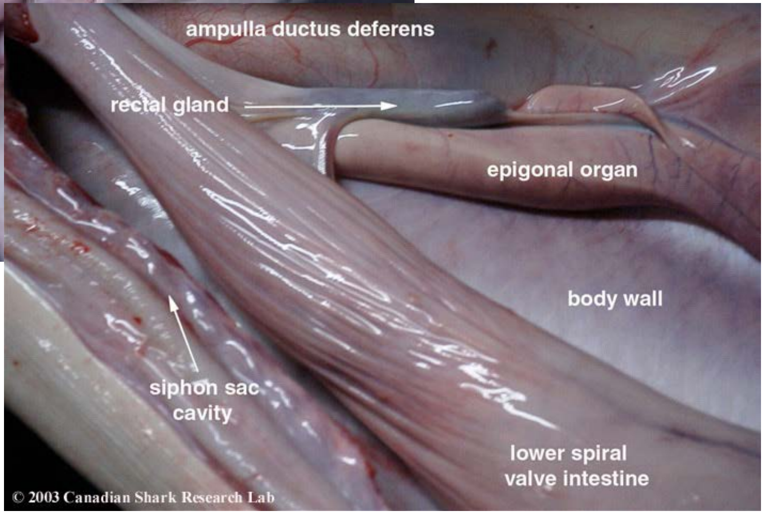


High cholesterol to phospholipid ratio in membrane minimizes urea entry

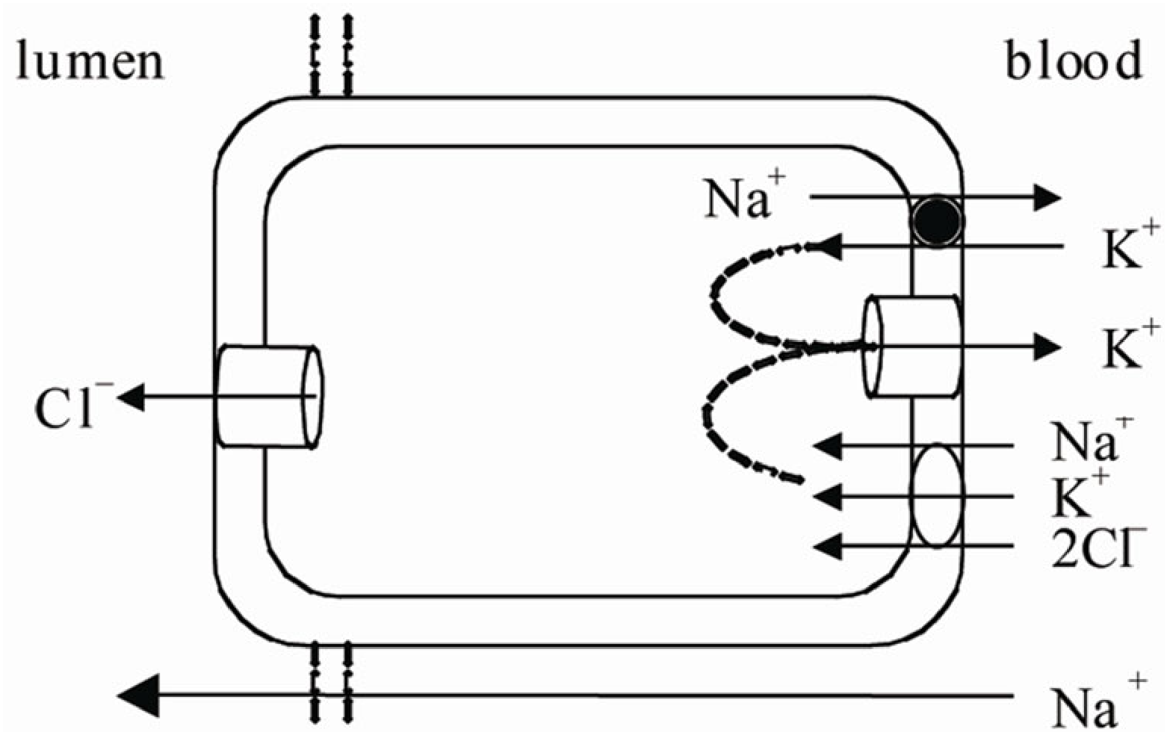
Net influx of Na^+ and Cl^- due to concentration gradient

Rectal gland





Ion regulation: Rectal gland



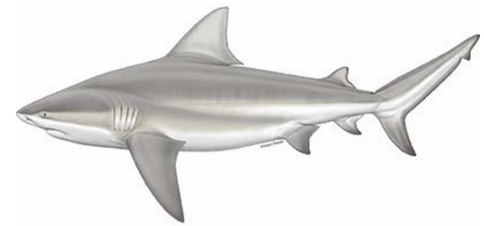
Rectal gland fluid

Species	Osmolarity (mOsmol.l−1)	Volume (ml.kg−1.h−1)	Na+ Conc. (mmol.l−1)	Urea Conc. (mmol.l−1)
Squalus acanthias	800	0.5	240	100
Scyliorhinus canicula	960	0.19	238	124
Hemiscyllium plagiosum	797	0.36	249	248
Raja erinacea (SW)	967	ND	180	ND
Dasyatis sabina (FW)	53	10	8	20
Pristin microdon (FW)	55	10	ND	14

Ion and urea regulation: Gut

- Net secretion of urea into chyme
- Net absorption of Na^+, Cl^- and water in stomach and intestines
- Divalent ions excreted

Euryhaline elasmobranchs

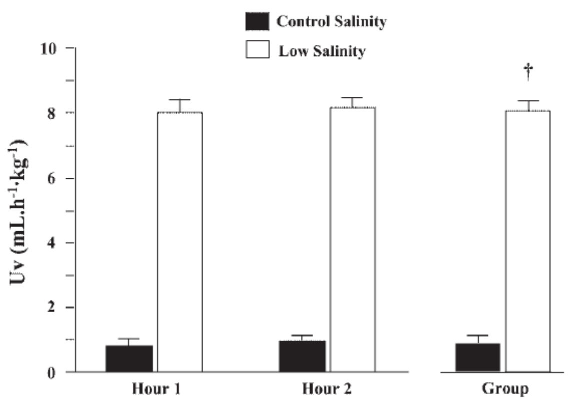


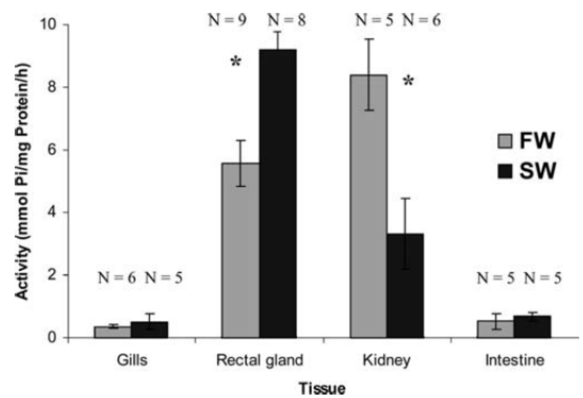
- Atlantic stingray (*Dasyatis sabina*)
- Tolerance: 2 – 36.7 ppt salinity

- Urine production increased 20 fold in 50% seawater

- Bull shark (*Carcharhinus leucas*)
- Tolerance: 0 – 35 ppt salinity

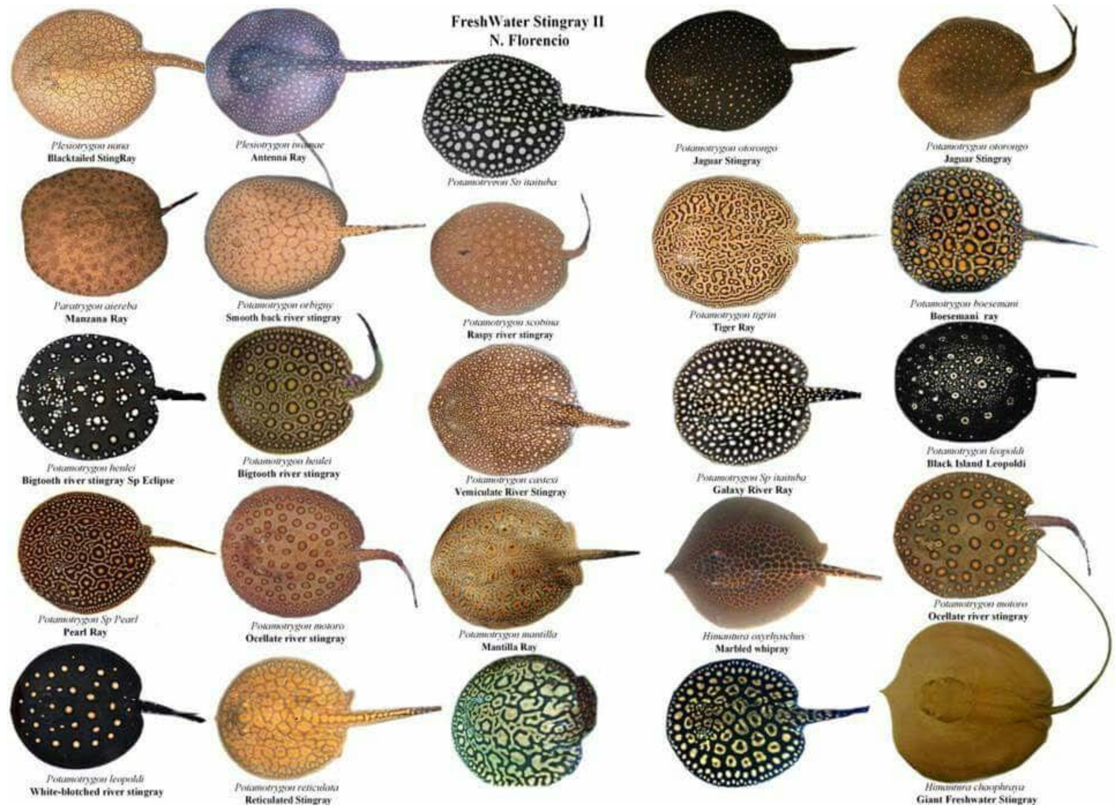
- Upregulate ion exchange and urea/TMAO production based on environment





Osmotic category	Salinity (mOsm/kg)	Na^+	K^+	Cl^-	Urea	TMAO	Plasma osmolality
Euryhaline migrating							
Dasyatis sabina[c]	SW	310	7	300	394		1034
Atlantic Stingray	FW	212	5	208	196		621
Carcharhinus leucas[d]	SW	304	6	315	293	47	940
Bull Shark	FW	221	4	220	151	19	595

Obligate freshwater elasmobranchs



Osmotic category	Salinity (mOsm/kg)	Na^+	K^+	Cl^-	Urea	TMAO	Plasma osmolality
Stenohaline FW							
Potamotrygon aiereba[f] Aiereba Stingray	FW	156	6	178	4.2	0	305