Water and Salt Physiology
Chapter 28

1. Animals in Freshwater

TABLE 28.1 The composition of blood plasma in some freshwater animals
The worldwide average composition of river water is shown for comparison.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Osmotic pressure (millimole per kg of H₂O)</th>
<th>Na⁺ (millimole per liter)</th>
<th>K⁺ (millimole per liter)</th>
<th>Ca²⁺ (millimole per liter)</th>
<th>Mg²⁺ (millimole per liter)</th>
<th>Cl⁻ (millimole per liter)</th>
<th>HCO₃⁻ (millimole per liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater mussel</td>
<td>44</td>
<td>16</td>
<td>0.5</td>
<td>6</td>
<td>0.2</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>(Anodonta cygnea)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snail (Viviparus hippopus)</td>
<td>76</td>
<td>34</td>
<td>1.2</td>
<td>5.7</td>
<td>&lt;0.5</td>
<td>31</td>
<td>11</td>
</tr>
<tr>
<td>Crayfish (Astacus fluviaticus)</td>
<td>436</td>
<td>212</td>
<td>4.1</td>
<td>16</td>
<td>1.5</td>
<td>199</td>
<td>15</td>
</tr>
<tr>
<td>Mosquito larva (Culex nigripalpis)</td>
<td>266</td>
<td>100</td>
<td>4.2</td>
<td>—</td>
<td>—</td>
<td>51</td>
<td>—</td>
</tr>
<tr>
<td>Brown trout (Salmo trutta)</td>
<td>326</td>
<td>161</td>
<td>5.3</td>
<td>6.3</td>
<td>0.0</td>
<td>119</td>
<td>—</td>
</tr>
<tr>
<td>Frog (Rana esculenta)</td>
<td>237</td>
<td>109</td>
<td>2.6</td>
<td>2.1</td>
<td>1.3</td>
<td>78</td>
<td>27</td>
</tr>
<tr>
<td>River water</td>
<td>0.5–10</td>
<td>0.4</td>
<td>0.1</td>
<td>0.8</td>
<td>0.2</td>
<td>0.2</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Fig 28.1 Water–salt relations in a freshwater animal

1. Hyperosmotic
2. Dilution of blood plasma
3. Dilute urine
4. Decrease permeability
5. Ions from food

Fig 28.8a Water–salt relations in freshwater teleost fish

(a) Freshwater teleost
- Salt loss by diffusion
- Water uptake by osmosis
- Gills
- Active uptake of Na⁺ and Cl⁻
- Salt and water in food
- Large amounts of urine, very hyperosmotic to plasma

(b) Freshwater teleost
- Water uptake by osmosis
- Active uptake of Na⁺ and Cl⁻
Animals in Saltwater

TABLE 28.3 The composition of the blood plasma or other extracellular body fluids in some marine invertebrates and hagfish

All these animals are isosmotic to seawater. The ion concentrations listed are for animals living in seawater of the composition specified in the last row of the table.

<table>
<thead>
<tr>
<th>Animal and body fluid</th>
<th>Na⁺</th>
<th>K⁺</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>Cl⁻</th>
<th>SO₄²⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mussel (Mytilus), blood plasma</td>
<td>474</td>
<td>12.0</td>
<td>11.9</td>
<td>52.6</td>
<td>553</td>
<td>28.9</td>
</tr>
<tr>
<td>Squid (Loligo), blood plasma</td>
<td>456</td>
<td>22.2</td>
<td>10.6</td>
<td>55.4</td>
<td>570</td>
<td>8.1</td>
</tr>
<tr>
<td>Crab (Carcinus), blood plasma</td>
<td>531</td>
<td>12.3</td>
<td>13.3</td>
<td>19.2</td>
<td>557</td>
<td>16.5</td>
</tr>
<tr>
<td>Sea urchin (Echino), coelom fluid</td>
<td>474</td>
<td>10.1</td>
<td>10.6</td>
<td>53.3</td>
<td>557</td>
<td>28.7</td>
</tr>
<tr>
<td>Jellyfish (Aurelia), mesogloial fluid</td>
<td>474</td>
<td>10.7</td>
<td>10.0</td>
<td>53.0</td>
<td>580</td>
<td>15.8</td>
</tr>
<tr>
<td>Hagfish (Myxine), blood plasma</td>
<td>537</td>
<td>9.1</td>
<td>5.9</td>
<td>18.0</td>
<td>542</td>
<td>6.3</td>
</tr>
<tr>
<td>Seawater</td>
<td>478</td>
<td>10.1</td>
<td>10.5</td>
<td>54.5</td>
<td>558</td>
<td>28.8</td>
</tr>
</tbody>
</table>

Hagfish Osmoregulation

1. Marine and Stenohaline
2. Isosmotic “vertebrates”
3. Osmoconformers
4. No influx or efflux of water
5. Ionic regulation like marine invertebrates.
Marine Teleosts

Class Osteichthys
1. Ancestor from freshwater
2. Hypoosmotic, regulate water and ions.
   A. Slightly higher osmotic concentration than freshwater fish.
3. Relatively impermeable skin

Marine teleosts
1. Salts must be excreted at higher concentration than that of seawater
   A. Teleost kidneys cannot do this
2. Marine bony fish produce scant isosmotic urine
   A. Urine ion concentrations differ from seawater
   B. Kidneys mostly excrete magnesium and sulfate
3. Bony fish excrete ions by active transport out of the gills.
4. Chloride cells in the gills excrete Cl, Na
Marine air-breathing vertebrates

1. Terrestrial animals that are osmotically isolated from environment
2. Reptiles
   A. Remove salt using salt glands in their heads
      a. Produce concentrated solutions of Na and Cl
   B. Crocodiles have salt glands on tongue
   C. Unknown if any marine reptile normally drinks salt water

Marine birds

1. Salt glands near eyes that connect with nasal passage (Fig 28.9)
2. salt flow counter current to flow of blood
3. 
4. Can secrete a huge amount of salt and fluid, especially for their size

MARINE MAMMALS
Kidneys produce urine hypertonic to sea water but humans cannot drink seawater (lose more water to get rid of excess salt), whales can

<table>
<thead>
<tr>
<th>Mammalian blood plasma</th>
<th>300 mosmols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human urine</td>
<td>1200 mosmols</td>
</tr>
<tr>
<td>Whale urine</td>
<td>1200-1500 mosmols</td>
</tr>
<tr>
<td>Banner-tailed K-rat urine</td>
<td>2700 mosmols</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sea water consumed</th>
<th>Urine produced</th>
<th>Water balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (ml)</td>
<td>Cl intake (mmol/l)</td>
<td>Volume Cl in urine (ml)</td>
</tr>
<tr>
<td>Human 1000</td>
<td>535</td>
<td>1350</td>
</tr>
<tr>
<td>Whale 1000</td>
<td>535</td>
<td>650</td>
</tr>
</tbody>
</table>
Marine sharks and rays

1. hyposmotic (1/3) in regard to salts
2. slightly hyperosmotic
   A. retain urea
   B. Net water in.
3. urea concentration is 100 times mammals
4. trimethylamine oxide (TMAO) for osmotic balance
   A. urea destabilizes and inhibits enzymes
   B. TMAO counteracts
5. Urea and TMAO are retained by the kidneys

Marine sharks and rays

1. ionically regulate
2. salts diffuse in
   A. sodium half that of seawater
   B. sodium is excreted by kidneys, gills, and rectal gland or feces
3. water flow into gills used for excretion
Responses to variations in salinity

1. Stenohaline
2. Euryhaline
3. Fig 26.4 Salinity trends in an estuary
4. Osmoconformers
5. Osmoregulators

Figure 28.11 Types of osmotic regulation

Brackish water animals are often euryhaline (Fig. 27.5)

1. Hyper-osmotic: regulate at low [H$_2$O], isoosmotic at high [H$_2$O]
2. Hyper-hyposmotic: regulate at low and high [H$_2$O]

Catadromic and Anadromic fish

1. Catadromous
   A. *Anguilla rostrata* reproduce in Sargasso Sea, juveniles return to salt marshes; mature and live in freshwater
2. Anadromous
   A. Salmonids born in freshwater, migrate to sea, return to spawn
3. change drinking and urinating
4. reverse active transport
salt water lampreys.

1. perform as saltwater adapted bony fishes
   A. gain water by drinking and feeding
   B. no urine flow
   C. chloride cells pump Na+ and Cl- out

Lamprey Osmoregulation

1. marine and fresh water
2. Marine are anadromous
3. In freshwater, perform as freshwater bony fishes
   A. high volume of urine
   B. chloride cells in gills import Na+ & Cl-

fresh-water elasmobranchs

1. some travel up rivers
2. very few spend whole life in freshwater
3. urea levels are 1/3 of those in marine sharks
4. completely freshwater elasmobranchs have urea levels similar to those of freshwater teleosts (low)
OSMOREGULATION IN THE TERRESTRIAL ENVIRONMENT

1. Advantage is abundant oxygen
2. Disadvantage is major water loss
3. Two phyla (arthropods and vertebrates) have successfully invaded land
4. Other phyla usually stay in moist environments

Moist-skinned animals

1. Earthworms
   A. Lose water by skin evaporation in air
   B. Live in damp soil where air pockets are fully saturated
   C. Osmoregulate like a fresh water animal
2. Amphibians
   A. Lose water by skin evaporation
   B. In water they osmoregulate like freshwater animals
   C. Must live near water or in humid air

Amphibians

1. Skin is main organ of osmoregulation in adults
   A. Actively pump in sodium
   B. Chloride follows passively
2. Copious urine like freshwater fish
Desert Frogs
1. estivate underground during drought
2. breed after rainfall
3. Australian frog
   A. stores about 30% of water as dilute urine in bladder
   B. slowly dehydrate
   C. urea concentrations get very high

Evaporation in Frogs and Toads
1. evaporate at about the same rate.
   A. A few have relatively impermeable skin or secrete wax. (Arboreal frogs of the genus *Phyllomedusa*, Figure 28.22)
   B. Some excrete uric acid instead of urea.

Arthropods: Insects and Arachnids
1. Can live in completely dry environments for their whole lives
2. Water losses
   A. Evaporation from body surface and respiratory organs
   B. Feces and urine
3. Water gains
the association between Total Evaporative Water Loss and body mass in birds

1. Figure 28.18: total rate of evaporative water loss is an allometric function of body size
2. From mesic areas is:
   A. $\log \text{TEWL} = -0.438 + 0.661 \log M$
3. From arid regions, the equation is:
   A. $\log \text{TEWL} = -0.754 + 0.750 \log M$

$\text{TEWL} = 0.18 \times \text{Mass}^{0.75}$

$\frac{\text{TEWL}}{\text{Mass}} = 0.18 \times \text{Mass}^{-0.25}$

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JOSEPH B. WILLIAMS; A PHYLOGENETIC PERSPECTIVE OF EVAPORATIVE WATER LOSS IN BIRDS

Figure 28.20 Urine concentrating ability in mammals: The maximum concentration is in part a function of body size

Figure 28.24 A kangaroo rat water budget