

Osmoregulation in Aquatic Vertebrates

Osmoregulation is a process that regulates the osmotic pressure of fluids and electrolytic balance in organisms. In animals, this process is brought about by osmoreceptors, which can detect changes in osmotic pressure. Humans and most other warmblooded organisms have osmoreceptors in the hypothalamus. Besides the brain, osmoregulators are also found in the kidneys.

Definitions

When the osmotic pressure of the organism's body fluids is equivalent to the osmotic pressure of the medium in which they live, the organism is called isoosmotic or iso-osmotic such as most marine invertebrates have same osmotic pressure as the sea water. In Greek, the word *iso* means equal. The animal responds in different ways to the change in the concentration of the medium. Those animals which remains iso-osmotic (same osmotic pressure) with the medium by changing and maintaining equal osmotic concentration of their body fluids to the medium are called osmoconformers i.e. animals which conforms there body fluid's osmotic concentration with that of the external medium.

In contrast, some animals such as a marine crab regulate and maintain its osmotic concentration irrespective of changes in the osmotic concentration of the medium; these animals are called as osmoregulators. A marine crab is a typical example of an osmoregulator which when moved from marine water to dilute brackish water inspite of the osmotic concentration of brackish water, maintains highest salt concentrations in its body fluids.

Most fresh-water organisms are called as hyperosmotic, as they have higher osmotic concentration in their body fluids than the medium. On the other hand, some fresh-water animals have osmotically more concentrated body fluids than the medium and these organisms are called as hyposmotic or hypo-osmotic.

In some aquatic animals, even if it's isosmotic with the external medium, there is usually a substantial difference between concentration of various individual solutes in the animal's body fluid and in the medium. These differences in the solute concentrations are carefully regulated and termed as ionic regulation. Both osmoconformers as well as osmoregulators to some extent exhibit ionic regulation.

Some aquatic animals have a limited tolerance and cannot tolerate the variations in the salt concentration of medium in which they live, they are known as stenohaline, derived from two different Greek words *stenos* and *halos* meaning close, narrow and salt respectively. For example, a euryhaline animal can migrate from marine water and penetrate into brackish water and survives to its best. In extreme cases these marine euryhaline animals can even tolerate longer or shorter periods in fresh-water medium. The fresh-water animals are called as euryhaline when they tolerate substantial increase in salt content of water.

Need for Osmoregulation

Biological systems constantly interact and exchange water and nutrients with the environment by way of consumption of food and water and through excretion in the form of sweat, urine, and feces. Without a mechanism to regulate osmotic pressure, or when a disease damages this mechanism, there is a tendency to accumulate toxic waste and water, which can have dire consequences. Mammalian systems have evolved to regulate not only the overall osmotic pressure across membranes, but also specific concentrations of important electrolytes in the three major fluid compartments: blood plasma, extracellular fluid, and intracellular fluid. Since osmotic pressure is regulated by the movement of water across membranes, the volume of the fluid compartments can also change temporarily. Because blood plasma is one of the fluid components, osmotic pressures have a direct bearing on blood pressure.

Types of Osmoregulation

There are two major types of osmoregulation: **Osmoconformers and Osmoregulators**

Osmoconformers

Osmoconformers: are organisms that try to match the osmolarity of their body with their surroundings. In other words, these organisms maintain the same osmotic pressure inside the body as outside water. They conform either through active or passive means. Most marine invertebrates such as starfish, jellyfish and lobsters are osmoconformers.

Osmoregulators:

Osmoregulators are organisms that actively regulate their osmotic pressure, independent of the surrounding environment. Many vertebrates, including humans, are osmoregulators. Most freshwater fish are considered to be osmoregulators too.

Sea water is hypertonic in comparison to body fluids. Organisms such as goldfish that can tolerate only a relatively narrow range of salinity are referred to as stenohaline. About 90 percent of all bony fish are restricted to either freshwater or seawater. They are incapable of osmotic regulation in the opposite environment. It is possible, however, for a few fishes like salmon to spend part of their life in fresh water and part in sea water. Organisms like the salmon and molly that can tolerate a relatively wide range of salinity are referred to as **euryhaline organisms**. The opposite of euryhaline organisms are **stenohaline** ones, which can only survive within a narrow range of salinities. Most freshwater organisms are stenohaline, and will die in seawater, and similarly most marine organisms are stenohaline, and cannot live in fresh water.

Osmoconformers match their body osmolarity to their environment actively or passively. Most marine invertebrates are osmoconformers, although their ionic composition may be different from that of seawater. Osmoregulators tightly regulate their body osmolarity, which always stays constant, and are more common in the animal kingdom.

Osmoregulators actively control salt concentrations despite the salt concentrations in the environment. An example is freshwater fish. Some fish have evolved osmoregulatory mechanisms to survive in all kinds of aquatic environments. When they live in fresh water, their bodies tend to take up water because the environment is relatively hypotonic, as illustrated in Figure 1. In such hypotonic environments, these fish do not drink much water. Instead, they pass a lot of very dilute urine, and they achieve electrolyte balance by active transport of salts through the gills.

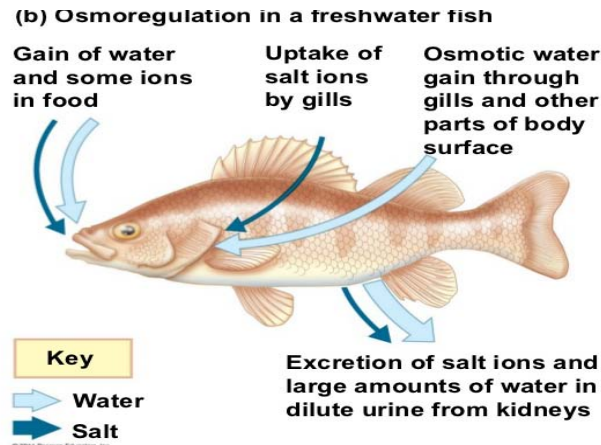


Figure1 Osmoregulation in a freshwater environment.

When they move to a hypertonic marine environment, these fish start drinking sea water; they excrete the excess salts through their gills and their urine, as illustrated in Figure 2. Most marine invertebrates, on the other hand, may be isotonic with sea water (osmoconformers). Their body fluid concentrations conform to changes in seawater concentration. Cartilaginous fishes' salt composition of the blood is similar to bony fishes; however, the blood of sharks contains the organic compounds urea and trimethylamine oxide (TMAO). This does not mean that their electrolyte composition is similar to that of sea water. They achieve isotonicity with the sea by storing large concentrations of urea. These animals that secrete urea are called ureotelic animals. TMAO stabilizes proteins in the presence of high urea levels, preventing the disruption of peptide bonds that would occur in other animals exposed to similar levels of urea. Sharks are cartilaginous fish with a rectal gland to secrete salt and assist in osmoregulation.

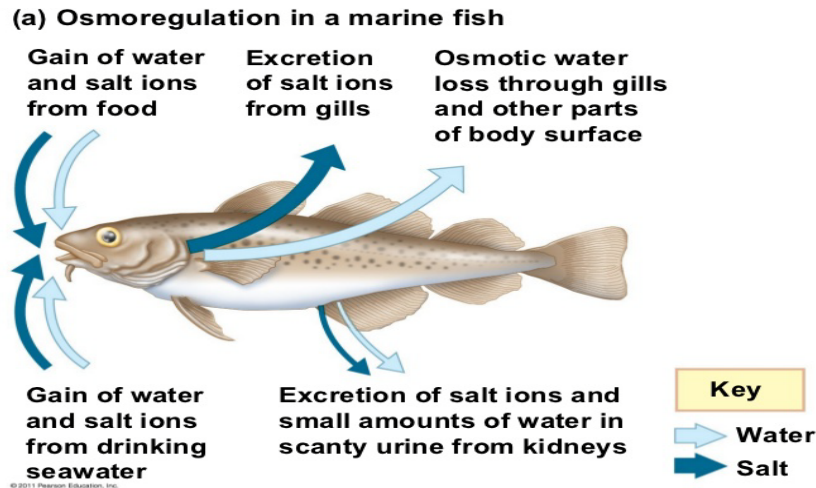


Figure2 Osmoregulation in a saltwater environment.

Osmoregulation in Freshwater Vertebrates

Freshwater Fish

Freshwater fishes are hypertonic to their surrounding environment, which means that the concentration of salt is higher in their blood than their surrounding water. They absorb a controlled amount of water through the mouth and the gill membranes. Due to this intake of water, they produce large quantities of urine through which a lot of salt is lost. The salt is replaced with the help of mitochondria-rich cells in the gills. These cells absorb salt into the blood from the surrounding water.

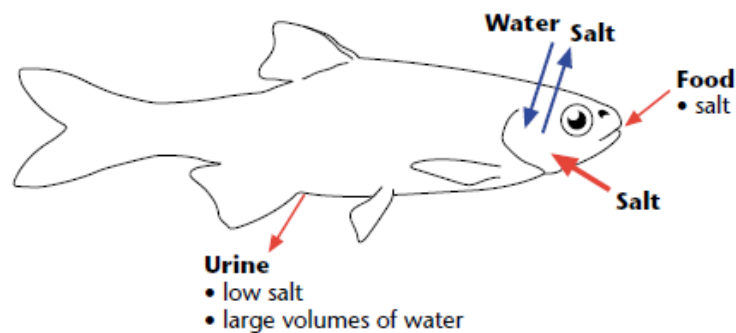


Figure 1 Osmoregulation in a freshwater fish. The net osmotic gain of water and diffusional loss of salt across the gills is balanced by excretion of relatively dilute urine, active uptake of salt across the gill, and possibly some ingestion of salt in the food. Blue arrows represent passive movements of salt and water, and red arrows indicate active pathways of osmoregulation.

Freshwater Amphibians

In those species of amphibians that have tadpoles as larvae, the osmotic adaptations to life in fresh water are basically the same as those for fishes. In amphibians (adult frogs, salamanders,

etc.) that are gill-less, the skin has evolved salt transport pathways similar to those in the gills of fishes or tadpoles. Indeed, much early work on the biophysical mechanisms of Na⁺ transport involved study of the movement of Na⁺ across frog skins.

Freshwater Reptiles

Freshwater reptiles are relatively uncommon; turtles are the only group that has been studied in any detail. In reptiles, net influx of water, which is minimized by the thick skin, is balanced by variable urine flows. Urinary salt loss is minimal (because of salt reabsorption by the distal renal tubule), as is diffusional loss across the skin. What salt is lost is balanced by either salt in the food or, in some species, active extraction of salt from water drawn into either the mouth or anus, but the salt transport mechanisms involved are unknown.

Freshwater Birds and mammals

In these very impermeable animals (cormorants and otters, for instance), osmotic uptake of water is minimal, balanced by increased urine flows if necessary, and any salt lost in the urine is compensated for by food. There is no evidence for any skin uptake of salt from the environment.

Osmoregulation in Marine Vertebrates

Marine Fish

Compared to freshwater fish, marine fish face the opposite problem. Sea water is hypertonic in comparison to body fluids. They have a higher concentration of water in their blood than their surrounding environment. Consequently, it results in the tendency to lose water and absorb the salt. To get around this problem, marine fish drink large quantities of water and restrict urination. Another additional energy expenditure also arises as these organisms actively need to expel salt from the body (through the gills).

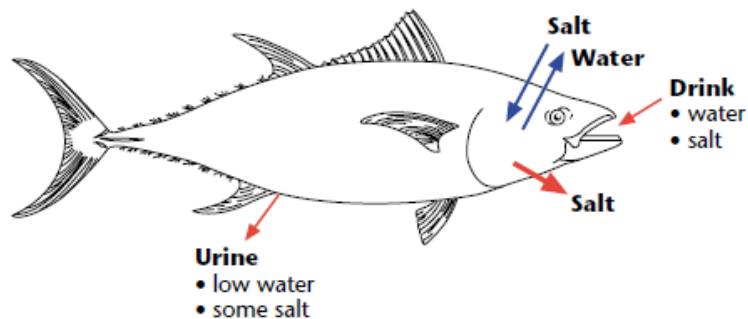


Figure 2 Osmoregulation by a marine teleost fish. The net osmotic loss of water and diffusional gain of salt across the gills is balanced by ingestion of sea water, production of small volumes of urine that contains some salt, and active extrusion of salt across the gill. Blue arrows represent passive movements of salt and water, and red arrows indicate active pathways of osmoregulation. See text for details. Outline drawing of a tuna was redrawn

Marine Amphibians

Amphibians are rarely associated with sea water. One exception is the crab-eating frog of southeast Asia, whose tadpole osmoregulates like a marine teleost and whose adult

osmoregulates like an elasmobranch, by storing urea. How salt is secreted by these animals is not known.

Marine Reptiles

Marine reptiles are common, and include turtles, snakes, lizards, crocodiles, and even alligators that may have entered the marine environment. In all cases, the desiccating effects of sea water are minimized by their thick skin, but the salt in their food and ingested sea water must be excreted. The absence of a loop of Henle precludes net renal salt secretion, so extrarenal pathways have evolved. In all cases, the secretory tissue is in the head region, with orbital salt glands in turtles and lizards, sublingual glands in sea snakes, and supralingual glands in crocodiles and to a much lesser extent, alligators. The specific mechanisms of net salt secretion by these salt glands is unknown, but assumed to be similar to that described for the teleost gill tissue and shark rectal gland.

Marine Birds

Marine birds have evolved the same strategies as the reptiles, including an orbital salt secretory gland (termed anasal gland because its secretory fluid drips from the nasal openings). The mechanisms of salt secretion have been better studied in birds than reptiles, and the published evidence suggests that the pathways are identical to those described for the teleost gill tissue and shark rectal gland. In addition to extrarenal salt secretion, bird kidneys are able to elaborate a slightly salty urine because of the origin of the loop of Henle.

Marine Mammals

Like the outer covering of marine reptiles and birds, the relatively impermeable skin of mammals avoids many of the osmoregulatory problems of life in sea water. The salt loading produced by ingestion of sea water and invertebrate food is offset by the presence of a loop of Henle, which allows the production of urine that is 2–3 times as salty as the blood. No extrarenal salt secretory mechanisms have been found, or are necessary.

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