Volume 3, Issue 2
February I 2025

Agri Roots
e- Magazine

www.agrirootsmagazine.in

ISSN: 2583-9071

Osmoregulation in Freshwater and Marine Water Fishes

ARTICLE ID: 0183

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The osmoregulatory mechanism in the body of fish adjusts the internal environment to the changing water content of the external environment. The alterations of the internal medium are performed by the coordinated functioning of the kidney, gills, and integument. In seawater fish, the gills and the kidneys play an important role in water retention by concentrating urine of relatively high osmolality. However, in freshwater fish, the kidney is more important in the excretion of the water taken from the hypertonic environment. The concentration of urine is low in the relatively hypotonic environment. In freshwater fish, through the functional activity of the kidney, the maintenance of the blood and tissues in a hypoosmotic climate and a good compensatory mechanism through the gills is

necessary—these mechanisms help to maintain acid-base balance in both conditions. Furthermore, the acid-base equilibrium is of greater importance in freshwater than in seawater fish. In freshwater, the increase in the influx of alkali ions occurs. These ions have to be transported in both directions through the gills. There is a loss of H^+ through an increase in CO_2 excretion only (the main system to excrete CO_2 is through the kidney). There are also effects on ammonia excretion, or ammonia is excreted in the undissociated form, i.e., by passive diffusion through the gills. Ammonia also changes from the undissociated form to the ammonium ion by an increase in NH_3.

Background of Osmoregulation In Fishes

The evolutionary history of osmoregulation in fishes traces back to the earliest vertebrates, which are believed to have originated in marine environments during the Cambrian period, over 500 million years ago. Early fishes likely developed osmoregulatory mechanisms to cope with the challenges posed by their surroundings. Over time, as fishes diversified and adapted to different aquatic environments, these mechanisms evolved to suit varying osmotic conditions.

Fishes are broadly categorized into marine and freshwater species, each facing unique osmoregulatory challenges:

1. **Marine Fishes:** These live in an environment with high salinity (hypertonic), where the concentration of salts in the water is greater than in their body fluids. Marine fishes face the risk of dehydration as water tends to move out of their bodies through osmosis.
2. **Freshwater Fishes:** These inhabit a low-salinity (hypotonic) environment where the salt concentration in the water is much lower than in their body fluids. Freshwater fishes are at risk of swelling and losing salts due to water influx through osmosis.
3. **Euryhaline Fishes:** Some species, like salmon, can tolerate a wide range of salinities and migrate between freshwater and seawater. They exhibit remarkable osmoregulatory flexibility.

Importance of Osmoregulation in Fishes

1. **Maintaining Cellular Function**: The balance of water and salts is essential for proper cellular processes, including enzyme activity, nutrient transport, and nerve function.
2. **Survival in Diverse Habitats**: Osmoregulation allows fishes to thrive in a wide variety of aquatic environments, from freshwater rivers and lakes to marine ecosystems and brackish waters.
3. **Adaptations to Extreme Environments**: Some fishes, such as those in hypersaline or ion-deficient waters, exhibit specialized osmoregulatory mechanisms to survive in extreme conditions. These adaptations include salt-excreting glands, specialized gills, and efficient kidneys.
4. **Energy Efficiency**: Effective osmoregulation minimizes energy expenditure by maintaining an optimal internal environment despite external fluctuations.
5. **Reproductive Success**: Proper osmoregulatory function is critical for reproductive processes, particularly for species that spawn in waters with salinity levels different from their usual habitat.

6. **Evolutionary Adaptations**: Osmoregulation has played a key role in the evolutionary success and diversification of fishes, contributing to their ability to colonize a wide range of ecological niches.

Osmoregulation In Freshwater Fishes

The fish gills and oral membrane allow them to continuously absorb water through diffusion because their internal environment is more concentrated than their surroundings (hyperosmotic to the surrounding medium). Large volumes of diluted urine are continuously expelled by well-developed kidneys as excess water. The pituitary hormones (Example: Arginine-Vasotocin; AVT) that cause blood pressure changes have an impact on the regulation of diuretic (urine-producing) processes. The kidneys of freshwater teleost have many glomeruli and are incredibly large for their body size. Additionally, the glomeruli are large enough to allow for the production of a significant amount of glomerular ultrafiltrate and, subsequently, a large volume of urine. Due to the large amount of urine they secrete, many freshwater teleost have developed a urinary. Despite the urine's low salt content, a considerable amount of salt is lost due to its frequent flow (Greenwell *et al.,* 2003). Additionally, salts are lost from the gill tissues through diffusion. Consuming salt in food and actively absorbing it through the gills balance these losses. Sodium and chloride pumps are found in specific cells found in gill lamellae. In order to maintain the ions' higher concentration in the body, these pumps—special enzymes—use energy to move the ions up their concentration gradient.

Osmoregulation In Marine Water Fishes

These fish are at risk of losing water from their bodies because the salt concentrations in their internal environment are about one-third that of their surroundings (they are hypo-osmotic to the surrounding water). It has been observed that osmosis causes some species to lose between 30 and 60% of the water they consume. The skin of marine teleost is impermeable to both water and salts to minimize water loss (Whittamore, 2012). In marine teleost, the quantity and size of glomeruli are either drastically diminished or eliminated. In addition, there isn't a water-impermeable distal convoluted tubule to save water. In addition, the glomerular filtration rate is significantly decreased, and less urine is produced to prevent the loss of water. As a result, freshwater teleost urine is much less concentrated than that of marine teleost.

In the past, marine teleost would consume a lot of seawater to stay hydrated. The rate of drinking varies by species and by salinity within species. The amount of seawater that marine species typically consume each day ranges from 7 to more than 35% of their body weight. This leads to consuming a lot of salt, which raises the body's salt content.

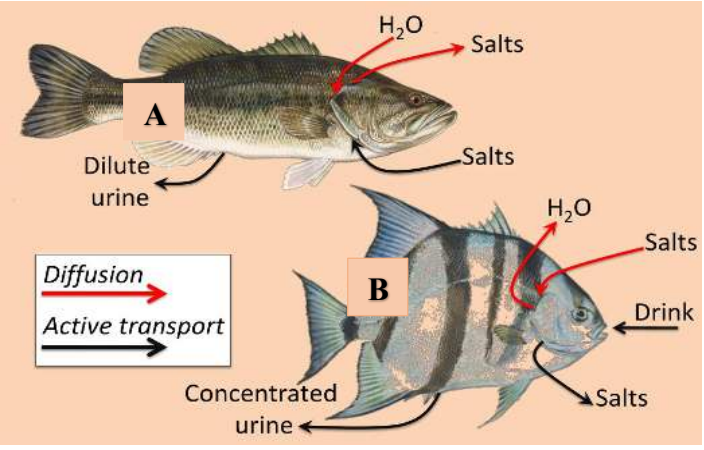

Figure: Osmoregulation in **A)** Freshwater Fish and **B)** Marine Water Fish

Kidney Function And Osmoregulation

Fish have evolved specialized kidney functions to address osmoregulatory challenges in both freshwater and marine environments. In freshwater, fish face the challenge of too much water entering their bodies because their body fluids are saltier than the surrounding water. To maintain osmotic balance, they produce large amounts of dilute urine, effectively removing the excess water absorbed through their skin and gills, this process helps prevent cellular swelling and ensures the fish's internal salt concentrations remain stable.

Marine fish face the challenge of osmoregulation in hypertonic seawater, where water loss can lead to dehydration. To manage this, their kidneys excrete divalent ions like calcium and magnesium, while gill ionocytes actively secrete monovalent ions such as sodium and chloride. Additionally, to conserve water, marine fish produce minimal, concentrated urine, as their kidneys cannot produce urine more concentrated than their body fluids. These renal adaptations are crucial for maintaining homeostasis in varying aquatic environments.

In a variety of aquatic settings, fish display a range of behavioural adaptations to cope with osmoregulatory challenges. For instance, euryhaline species like the short-finned molly (*Poecilia sphenops*) inhabit estuaries with varying salinities. Their capacity to withstand a broad range of salinities enables them to flourish in these fluctuating environments.

Behavioral Adaptation

In order to spawn, some species, such as salmon, migrate from the ocean to freshwater rivers. In order to adapt to the varying salinities they encounter throughout their life cycle, this migration necessitates significant physiological and behavioural changes (Lillywhite & Evans 2021).

Certain fish modify their behaviour to steer clear of harsh environmental circumstances that might interfere with osmoregulation. For example, some species might become more active at night in order to avoid the high temperatures and evaporation rates that cause salinity to rise during the day. These behavioural strategies are crucial for fish to maintain osmotic balance, ensuring their survival and reproductive success in environments with varying salinity levels.

Conclusion

Osmoregulation is a vital process that allows freshwater and marine fish to survive and thrive in environments with drastically different salinity levels. Freshwater fish face the challenge of excessive water entering their bodies and must excrete large amounts of dilute urine to maintain balance, while marine fish must counteract water loss by drinking seawater and excreting excess salts. These adaptations highlight the remarkable physiological mechanisms fish have developed to regulate their internal environment, ensuring survival in their respective habitats. Understanding osmoregulation not only deepens our knowledge of aquatic life but also provides insights into broader ecological and evolutionary processes.

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