

2.10 Salinisation of inland waters

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SUMMARY: *Salinisation is caused by natural factors (e.g. the soil types of catchment areas, atmospheric deposition and climate) and by anthropogenic activities (e.g. agriculture and mining). Some of the consequences are an increase of salt content, and the enrichment of single toxic ions in soils and waters. Aquatic organisms of single species are adapted to freshwater, marine and brackish environments; they use different energy-consuming mechanisms to regulate the ion concentrations. With an increase in salinisation the number of organisms increases but there is a decrease in diversity. Extremely saline environments are dominated by micro-organisms; this is the reason why we find relatively short food chains, low turnover rates and differences in matter flux in these environments. Nutrient-rich environments with low oxygen concentrations result. Investigations of artificially salted rivers showed that desalinisation is possible if the causes of the salinisation are halted - this means in many cases the implementation of technical developments (e.g. site adapted irrigation measures in agriculture; leaching procedures in mining).*

All the inland waters of the Earth together, including inland salt-water bodies, cover less than 2% of the Earth's surface, roughly $2.5\text{--}2.8 \times 10^6 \text{ km}^2$ (MEYBECK 1995). The total amount of water they contain amounts to about $2.8 \times 10^5 \text{ km}^3$, and it is unevenly distributed among the continents.

The underlying geological conditions with either carbonate or silicate rock, atmospheric deposition and climate all have an influence on the water and material budgets and their chemistry. Climate is the most important natural factor of influence. In humid climates precipitation dominates, and dilution occurs. In arid climates on the other hand evaporation is greater, water is »concentrated« (i.e., the remaining water carries higher ion concentrations), and salinisation occurs. But the concentration of ions in the water can also be increased as a result of anthropogenic activities. However, »anomalies« can also result in brown waters through the connection of cations with humic substances, and in lakes lying near the coast through spray and salt from seawater. Some inland waters are saltier than the sea. Organisms which have adapted to these (from a human point of view) extreme environmental conditions are termed – according to their salt tolerance – moderately to extremely halophilic or salt-loving, and the degree of salt tolerance additionally has an influence on the spectrum of potential habitats. Even though distinctly macroscopic environments such as salt lakes, saline springs, coastal salt marshes are rather rare, geological evidence shows us that salt lakes once covered very large areas. This supported the evolution of salt-tolerant or salt-loving types of organism. Looked at like this, saline environments and halophilic organisms have rather unfairly received comparatively little previous attention.

Salt content

The salt content or salinity is given by the sum of dissolved ions in the water – the cations sodium (Na^+), potassium

(K^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}) and the anions chloride (Cl^-), sulphate (SO_4^{2-}) and carbonate (CO_3^{2-}). Salinity is usually given as salt concentration [mg/litre], percentage [%] or conductivity [mS/cm]. Inland waters have a very broad spectrum of salt concentration from just a few to almost 330,000 mg of salt per litre of water; the global mean value is 120 milligrams of salt per litre (WETZEL 1983). Inland waters are classified according to the degree of salinity – three systems based on salt content are shown (Tab. 2.10-1).

Causes and problems

Salinisation denotes an increase in salinity due to natural or anthropogenic influences. According to TOWNSEND & HILDREW (1994) and PICKET & WHITE (1985) it is a disruption which brings about a change in the environmental conditions which in turn causes changes in the biological community.

Salinisation of still or flowing waters can have natural or anthropogenic causes:

- Introduction of waste water, for example waste water from mining activities in areas of chloride- or sulphur-containing rocks, or waste water from households, industry or agriculture,
- Irrigation of dry areas for agricultural use without drainage,
- Replacement of flat-rooted steppe vegetation by deep-rooting cultivated plants, which can cause salt to be brought to the surface (WILLIAMS 1987),
- Lack of or restriction of inflow or effluent,
- Climatic change coupled with increased evaporation and low levels of precipitation,
- Introduction of sulphur through SO_2 from fossil fuels, and
- Salts used for thawing (NaCl , MgCl_2).

While total salt content and ion composition vary greatly among different inland waters around the world, sea water

has a relatively constant salt content everywhere. The ion composition is the same in all the oceans, with a dominance of sodium and chloride ions. An ion composition similar to that of sea water is termed thalassic; one that is dissimilar is called athalassic. Athalassic waters are characterised by having had no contact with the sea in the recent geological past, or by having dried out during a marine phase prior to being reflooded.

In contrast to the inhabitants of marine environments, which enjoy a constant level of salinity, organisms in inland waters have to cope with the problem of fluctuation of the overall salt content. The salt causes a change in the osmotic pressure as well as influencing the toxicity of individual ions.

Biological effects of salinisation and adaptation by organisms

The ions listed in the section on salt content can be counted as »conservative« substances which the organisms do not need, or need only very little of, in comparison to what is on offer. In order to exist in an aquatic environment, organisms must be able to counterbalance the difference between the ion concentrations of their body fluids and the surrounding water, or to maintain it within a certain range. The following groups of organisms can correspondingly be distinguished:

- poikilosmotic organisms, sea-water dwellers – ion concentration of body fluids adapts to the surrounding water,
- hypertonic organisms, inhabitants of fresh or brackish water – ion concentration of body fluids is greater than that of the surrounding water,
- hypotonic organisms, inhabitants of extremely saline environments – ion concentration of body fluids is less than that of the surrounding water.

Regulation of the concentration of body fluids is an essential but often energy-intensive process; the amount of energy it requires increases with increasing salinity and has

a great effect on the aquatic biocoenosis. A change in the salinity of the surrounding water affects the ecosystem at different levels: it threatens the existence of individuals and populations, it affects generation time and reproductive ability and the complexity and functioning of the entire community. Salty water bodies create ecosystems with little diversity of species but large populations of some species – as regards the number of individuals, extreme values are often observed for particular species. Increasing salt concentration leads to fewer species but more salt-resistant forms. Fresh-water organisms can thus sometimes be replaced by »immigrants« from brackish or sea water. Bacteria and single-celled organisms often dominate over multi-celled organism types in salty environments.

Procaryotes, organisms without true cell nuclei, are widespread in freshwater and in extremely saline water. Some forms appear in either salt or freshwater, and others live in a region of fluctuation of salt levels and are adapted to these environments, e.g. through excretion of ectoin and betain. But especially in the case of bacteria, their presence often cannot necessarily be equated with bacterial activity. Nitrification is an example of a decomposition process which declines with increasing salinity, even though many nitrifiers may be present in the water.

Eucaryotes are plants and creatures with true cell nuclei and greater compartmentalisation through membranes. As regards plants, algae and in particular diatoms have been very well investigated. These react to changes in salt concentration as low as 100 mg chloride per litre (0.18 parts per thousand) through a change in the species composition. The presence of particular species is a measure of the salt content: halophobic species (fresh-water indicators) can be distinguished from halophile species (salt water indicators). The species that appear in salt water can be classified according to mesohaline forms, which prefer a moderately salty environment, and other forms which like a hyperhaline environment, i.e. can survive under extremely salty conditions. Higher plants often react very sensitively to changes

Tab. 2.10-1: Classification of inland waters (according to HAMMER 1986). The figures in the right-hand column give the salt content in g/l for the upper boundary of each category.

REDEKE-VÄLIKANGAS (1933)	Venice-System (1959)	BEADLE (1943) GAMMER et al. (1983)	Salt [g/l]	Organism
freshwater	freshwater	freshwater	0.5	
oligohalin		subsalin	3.0	
	oligohalin		4.0	
α-mesohalin	mesohalin		8.0	
β-mesohalin			16.5	
		hyposalin	20.0	
polyhalin	polyhalin		30.0	
	euhalin		40.0	
	> 40	mesosalin	50.0	
	hyperhalin	hypersalin	>50.0	

in salt concentration. Canadian waterweed (*Elodea canadensis*), for example, reduces its net photosynthesis production at such low levels of salt as 100 mg chloride per litre (0.18 parts per thousand). Magnesium and potassium chloride, in particular, have a toxic effect on the higher plants (NOBEL & KOHLER 1978). Water crowfoot (*Ranunculus fluitans*) also declines with increasing salt load.

For animal organisms, like plants, the degree of salt tolerance depends on the type of organism. Here too, the single-celled organisms (protozoa) seem to be much more tolerant than the multi-celled ones. The critical boundary seems to be around 5,000 mg chloride per litre of water (9 ppt). Among single-celled organisms, the ciliates have been well investigated; the free-swimming types are especially suitable as indicators and have been graded into five classes with respect to their salt tolerance. Multicelled animal organisms also react very sensitive to high concentrations of salts; for example, sponges, bryozoans and shellfish can disappear completely. Several types of fish, on the other hand, are insensitive to increased salt concentration. Among these are, e.g., diadromous fish, i.e. those which migrate from the sea to freshwater to spawn, like the salmon (*Salmo salar*) and sea trout (*Salmo trutta* f. *trutta*), or from fresh to salt water to spawn, such as the eel (*Anguilla anguilla*). Perches (*Tilapia*) are also classed as resistant.

Salty environments

Standing waters – lakes and pans

Natural salt lakes are formed as terminal lakes or volcanic lakes in connection with salt-bearing geological layers above the groundwater; when they dry out they leave so-called saltpans. Salty inflowing water, low precipitation and high evaporation favour their inception. Salt lakes are distributed world-wide (Fig. 2.10-1).

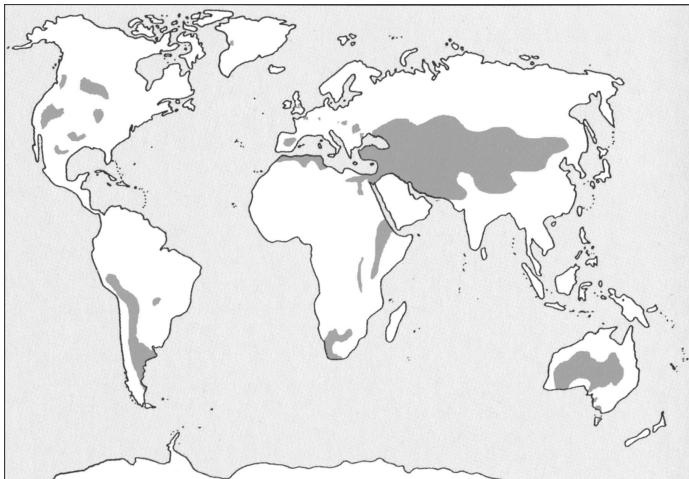


Fig. 2.10-1: World-wide distribution of salt lakes (after WILLIAMS 1996).

In some lakes the **deep water** (hypolimnion) is both thermally and chemically isolated from the above lying metalimnion. In this case it shows a higher salt content than the water layers above. The density gradient is therefore often greater than the thermal gradient and prevents a complete mixing (full overturning) of the water body. These water bodies, termed meromictic, have a non-mixing bottom layer – monimolimnion – which due to the lack of circulation often demonstrates increased nutrient concentrations but low oxygen content or even oxygen deficiency.

Soda lakes, which appear at Seewinkel in eastern Austria but also in Hungary, Asia, and East Africa, contain large amounts of sodium carbonate (soda) from salt-containing sediments; they are fed by rainwater and/or groundwater and are thus subject to seasonal changes (water depth, surface area, ion concentration). Because they have shallow basins – 30–50 cm in depth – such soda lakes can dry out if there is no connection to the groundwater and can only be refilled by heavy precipitation. At Seewinkel, »white« soda lakes with high soda concentrations have hardly any plant growth and contain many suspended particles; the »black« soda lakes, which have much vegetation, contain organic material and little soda.

Anthropogenic salinisation of inland water bodies and its consequences is discussed based on the examples of the **Aral Sea** (see Chapter 2.12), the **Dead Sea** and **Lake Chad**. The Aral Sea, fed by the rivers Amu-Darja and Syr-Darja, had an area of 68,000 km² and until 1960 was the fourth largest inland sea on Earth. Today it has practically ceased to exist. The cause of this was the diversion of water for agricultural irrigation combined with evaporation, which led to an intense salinisation of the remaining water. The problem is described in more detail in Chapter 2.11.

Another example is the **Dead Sea**, which is situated in the northern part of the African-Syrian fracture zone and

has a depth of 320 m. It lies in a basin without effluents, 392 m below sea level. Its water is an almost saturated salt solution with about 330 g of salt per litre. Chloride is the predominant anion, magnesium the predominant cation. Formerly, the freshwater flowing in from the River Jordan, because of its lesser density, formed a layer overlying the sea water to the north. This stratification prevented any deep circulation. But through increased use of the river water for irrigation purposes, this process has now almost ceased and full turnover was recorded for the first time in 1979.

For **Lake Chad**, on the southern edge of the Sahara, mean inflow has decreased by about 50% and precipitation by roughly 25% since 1970 as a result of the Sahel drought. At present it has an area of between 10,000 and 20,000 km² according to season. There is not an unambiguous connection with global climate change. At any rate, agricultural irrigation certainly plays a role in the reduction of the water volume in this case, too.

Flowing waters – Rivers and estuaries

Flowing waters have a natural salt content which is essentially influenced by soils and climate through precipitation and evaporation. In **estuaries**, i.e. the tidal parts of rivers, the actual salt content depends on the strength of the tide on the one hand and the volume of freshwater flowing downstream on the other. In this transitional zone hypertonic organisms are especially dominant – limnic and marine forms with only a narrow ecological tolerance die as a result of the change in salt content. This, in connection with the long residence time of the water body in an estuarine environment, can lead to oxygen deficiency during the summer months.

Anthropogenic salinisation of flowing waters is discussed with reference to the example of the Werra/Weser region in Germany. These rivers were salinised through waste water from the potassium industry. Particularly in the years after 1968 highly salty waste water was fed directly into the Werra leading to an increased salt concentration – up to 40 grammes of chloride per litre of water (72.26 ppt) were measured. This resulted in depletion of the river's fauna and flora. The »inharmonious« ion composition with greater K⁺ or Mg²⁺ content and profound variations of concentration due to the irregular influx of waste water had a toxic effect. In some highly salinised areas, marine and brackish-water organisms spread, such as the flea-crab *Gammarus tigrinus*, the green algae *Enteromorpha intestinalis* and the diatom *Chaetoceros mülleri*. Changes in technology and the closure of some enterprises led to a reduction of the salt content at the end of the 1990s number of fresh-water organisms has again begun to increase in many places, and there is an increase in species diversity.

Food webs

Increasing salt concentration means the presence of fewer species and thus shorter and less complex food chains; in other words, salt lakes deviate from the norm as regards food chains /structures.

In soda lakes, such as Lake Nakuru in Kenya, the primary producer is almost exclusively the blue algae *Spirulina platensis*. In this very shallow lake, the algae forms an excellent foodstuff for the flamingo (*Phoenicocnais minor*), which can scoop it up in its beak. In comparison to the algae, the number of flamingos is low. The flamingo shares the food with the coloured perch *Tilapia oreochromis*, which also feeds directly on the algae. No other species consumes the primary producer in significant amounts, so that in Lake Nakuru we observe the rare food chain of algae-fish and algae-bird.

In very salty lakes containing sodium chloride, such as the Great Salt Lake in Utah (USA) and in salt-works, the biological community consists chiefly of bacteria, the algae *Dunaliella salina* and the up-to-15 cm-long brine shrimp *Artemia*. Here too there is a very simple food chain, as is there for the soda lakes in the Austrian-Hungarian lowlands.

Regeneration of salinised waters after reduction of the salt load

The regeneration of salinised waters after the salt load has been reduced is possible. It takes place relatively slowly over a period of years and depends on the water regeneration time – the shorter this is, the more quickly the salt load is reduced. Flowing waters can therefore be expected to take less time to regenerate than lakes. In flowing waters the regeneration process is furthered, moreover, by recolonisation by organisms from unaffected sections of the river – upstream of a salt inflow, for example – which are continually reintroduced through drift or active migration.

Conclusion

The increasing world population together with higher expectations of living standards will increase water-related social conflict. This calls for a more careful use of this resource at various levels – for domestic use, in agriculture and for industrial purposes. Well-considered and moderate water use will be more important in future, and this must go hand in hand with technological progress – in agricultural production, for instance, but also in mining in the use of the solution mining process and of spoil-heaps. The condition of the waters polluted by the potassium industry in the Weser basin seems to be reversible, but the example of the Aral Sea shows us that salinisation can also be an irreversible process which not only results in the loss of biological diversity and functional capability, but carries with it numerous unpredictable social conflicts ♦