An overview of hybrid marine and lacustrine seas and saline lakes of the world

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Abstract

Water salinity is one of the major environmental factors influencing hydrobionts. Based on the concept of relativity and plurality of barrier salinity zones, barrier salinities are related to the development of the osmoregulatory capacities of hydrobionts and to the chemical composition of the water they inhabit. These zones are not of equal importance. The entire hydrosphere might be divided into freshwater, brackish water, marine and hyperhaline salinity zones and transitional zones between them. Approximate boundaries and corresponding barrier salinities are defined for all these zones. Revealing barrier salinity zones requires studying the osmoregulatory capacities of hydrobionts and the distribution of their salinity boundaries. We distinguish between four barrier salinities or horohalinicums for marine and continental waters: α (5–8‰), β (22–26‰), γ (45–50‰) and ™ (0.5–2‰). In metamorphized continental waters, barrier salinities are shifted to higher concentrations. Salinity barrier values can change the subsequent evolution of salinity adaptations and osmoregulation capacities. Maracaibo Lake is characterized by freshwater and freshwater–brackish water zones. Deepening of the lake shipping lane increased the salt flux, with the appearance of a brackish-water zone. This study proposes to distinguish hybrid lentic waterbodies that include the Baltic Sea, Black Sea, Sea of Azov and Maracaibo Lake, which have lost their lacustrine characteristics and are now characterized by intermixing marine (saline) and continental (fresh) waters.

Key words

barrier salinities, saline lakes, salinity, salinity zones, seas.

INTRODUCTION

Water salinity is one of the major environmental factors influencing hydrobionts. There are many saline lakes on our planet not connected to the world's oceans, as well as hybrid lacustrine/marine seas in which the salinity is changing smoothly from fresh water to marine and, in some cases, even to hyperhaline. This report discusses some such lakes and hybrid seas.

BARRIER SALINITIES

According to the conception of relativity and plurality of water barrier salinity zones (Aladin 1988), zones of barrier salinities are relative, on the one hand, to the degree of the osmoregulatory capacities of hydrobionts and, on the other hand, to the water chemical composition. There are several zones of barrier salinities (Tables 1–3; Figs 1 and 2), and they are not of equal importance.

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Revealing barrier salinity zones in the hydrosphere supposes first studying the osmoregulatory capacities of hydrobionts. The purpose of this study is to reveal types of osmotic relations of internal media with the environment, to find experimental limits of salinity tolerant ranges and to analyse data on salinity boundaries of hydrobiont distribution in the nature. For continental waters, positions of barrier salinities can be shifted to higher values because of difference in ion composition, when the proportion of divalent ions is higher, compared with waters with oceanic ion composition (Fig. 3; Aladin 1983, 1989).

The position and width of barrier salinities ranges do not only depend on the physicochemical properties of water. The barrier salinities values can change following evolution of salinity adaptations and the osmoregulation capacities of aquatic plants and animals.

SALINITY ZONES

The hydrosphere of our planet can be conditionally divided into freshwater, brackish water, marine and

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Table 1. Characteristic of barrier salinity zones or horohalinicums for the ocean and selected seas

Barrier salinity	Oceanic waters (‰)	Caspian Sea (‰)	Aral Sea (‰)
α-horohalinicum (brackish waters)	5–8	7–11	8–13
β-horohalinicum (polyhaline waters)	22–26	26–30	27–32
γ-horohalinicum (hyperhaline waters)	45–50	46–51	47–52
δ-horohalinicum (fresh waters)	0.5–2	0.5–2.5	0.5–3

Table 2. Percentage of areas of different barrier salinity zones (horohalinicums) in hybrid marine/lacustrine seas and saline lakes

	Horohalinicums			
	α (%)	β (%)	γ (%)	δ (%)
Baltic Sea	62	4	<0.01	6
Black Sea	0.02	<0.01	<0.01	0.2
Sea of Azov	7	1	1	<2
Caspian Sea	13	<0.01	<0.01	5
Aral Sea (before 1960)	88	<0.01	<0.01	<1
Modern Aral Sea (Small Aral)	1	–	–	<0.1

Table 3. Percentage of total areas constituted by all barrier salinity zones (horohalinicums) in hybrid marine/lacustrine seas and saline lakes

Sea/lake	Total (%)
Baltic Sea	72
Black Sea	<1
Sea of Azov	11
Caspian Sea	18
Aral Sea (before 1960)	89
Modern Aral Sea (Small Aral)	1

hyperhaline zones. Between these four basic zones, there are transitional zones. Based on the following main principles of relativity and plurality of salinity barrier zones (Aladin 1988), the following approximate ranges of all basic and transitional salinity zones were suggested for oceanic, Caspian and Aral waters (Table 4, Fig. 4).

The marine zone occupies more than 95% of the hydrosphere surface. The freshwater zone occupies <3%, whereas the brackish water and hyperhaline zones each occupy about 0.5%. Each transitional zone occupies <0.5%. Portions of all salinity zones in the studied hybrid marine/lacustrine seas and saline lakes are illustrated in Figure 5.

ARAL SEA

During the first half of the 20th Century, the Aral Sea was a single terminal water body of two rivers in the arid zone. Its main portion was brackish (Fig. 6), with specific aboriginal brackish water ecosystems. Decreasing water levels and increasing salinization of the Aral Sea have been occurring since the 1960s. As a result of the structure of its depression, the Aral Sea began to subdivide into several residual water bodies. In 1988–1989, after the water level decreased by 13 m, the Aral Sea subdivided into two polyhaline terminal lakes with marine ecosystems – the Large and Small Aral (Fig. 7). Only widely euryhaline faunal species remained because of the increasing salinization and the introduction of exotic species. Piscifauna consisted of introduced species of marine origin. In spring 1990, the water level of the Small Aral increased, causing and initiation of water flows to the Large Aral. There was a threat that the mouth of the inflowing Syr Darya would shift to the Large Aral. In August 1992, a dike was built in the Berg Strait. The increasing salinity of the Small Aral ceased, with the salinity beginning to decrease, with a favourable influence on the fauna. A transitional brackish water-marine salinity zone formed. In April 1999, a storm destroyed the dike. Construction of a new structurally sound dike commenced in 2004, being completed in autumn 2005. After the subdivision of the Aral Sea, the increasing salinization and decreasing water level in the Large Aral accelerated. The Large Aral divided into the Western Aral, Eastern Aral and Tschebas Bay (Fig. 8). The salinity in the eastern basin is increasing faster than in the western basin. In the late 1990s, the Large Aral became hyperhaline, with specific fauna. Some invertebrate species inhabiting saline waterbodies in the Aral Sea region moved into the Large Aral via natural water routes. The brine shrimp (*Artemia parthenogenetica*) became the predominate zooplankton (Aladin & Plotnikov 2008; Aladin *et al.* 2008).

The original brackish-water ecosystem of the Aral Sea has clearly disappeared because of the salinization. The Aral Sea was the largest hybrid marine/lacustrine sea of athalassic type. The Baltic Sea was the largest hybrid marine/lacustrine sea of thalassic type. Brackish-water ecosystems cover up to 60% of the unique Baltic Sea. In the Aral Sea, they covered up to 90%.

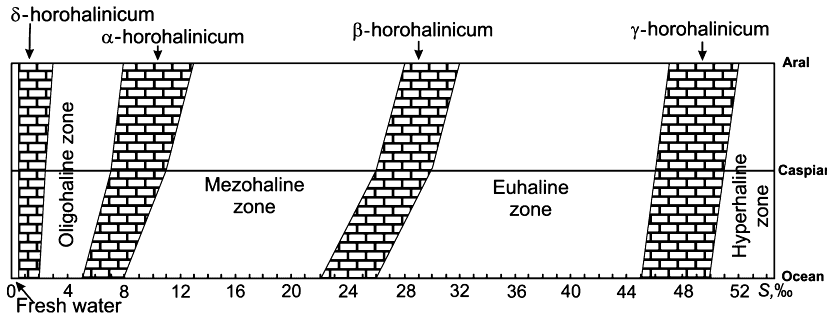

Fig. 1. Position of barrier salinity zones or horohalinicums for the ocean and selected seas.

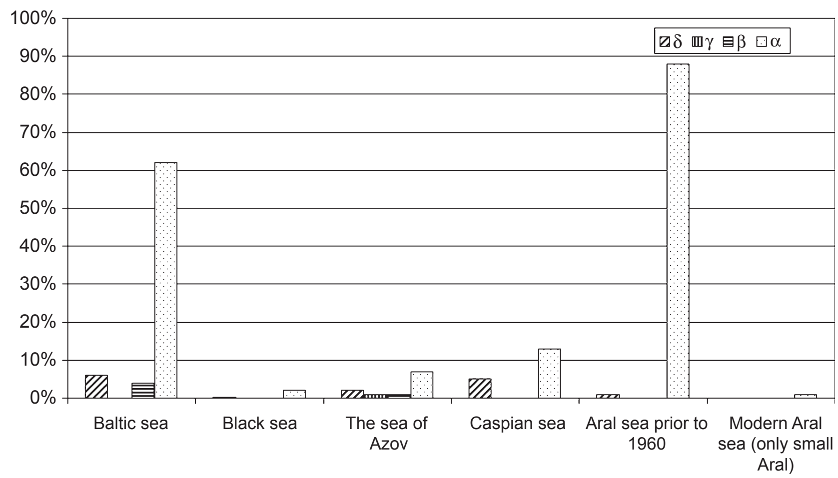

Fig. 2. Percentage of areas of different barrier salinity zones (horohalinicums) in hybrid marine/lacustrine seas and saline lakes.

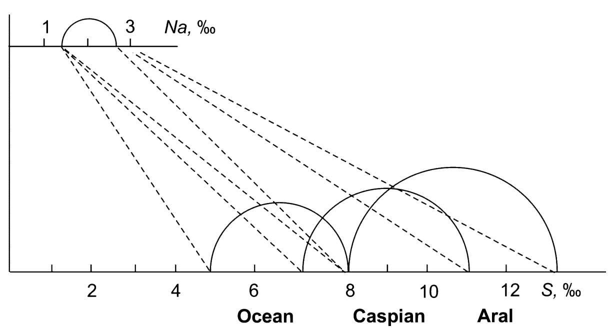

Fig. 3. Critical salinity or α-horohalinicum shift to higher concentrations in waters of Caspian and Aral Seas as compared with oceanic water.

Table 4. Ranges of salinity zones

Zones	Ocean (‰)	Caspian (‰)	Aral (‰)
Basic fresh water	0–2	0–2.5	0–3
Transitional fresh water–brackish water	2–5	2.5–7	3–8
Basic brackish water	5–8	7–11	8–13
Transitional brackish water-marine	8–26	11–28	13–29
Basic marine	26–40	28–41	29–42
Transitional marine-hyperhaline	40–50	41–50.5	42–51
Basic hyperhaline	>50	>50.5	>51

In the case of the Aral Sea, diversion of riverine waters for irrigation purposes allowed increased cotton and rice production. Unfortunately salinization of irrigated lands prevented development of sustainable agriculture in this area (Micklin & Aladin 2008).

Desiccation of the Aral Sea has caused severe consequences. Greatly, reduced river flows ended the spring floods that previously sustained wetlands with fresh water and enriched sediment. The number of fish species in the lakes decreased from 32 to 6 because of increasing salinity and loss of spawning and feeding grounds. Commercial fisheries were lost. Shipping on the Aral Sea also ceased because the shoreline receded many kilometres from the major ports into the sea bed. Groundwater levels decreased as a result of falling lake levels, thereby also intensifying desertification. The climate also changed up to 100 km beyond the original shoreline, with summers now being hotter, winters being colder and humidity lower (resulting in less rainfall). The growing season is shorter, and drought is more common (Micklin & Aladin 2008).

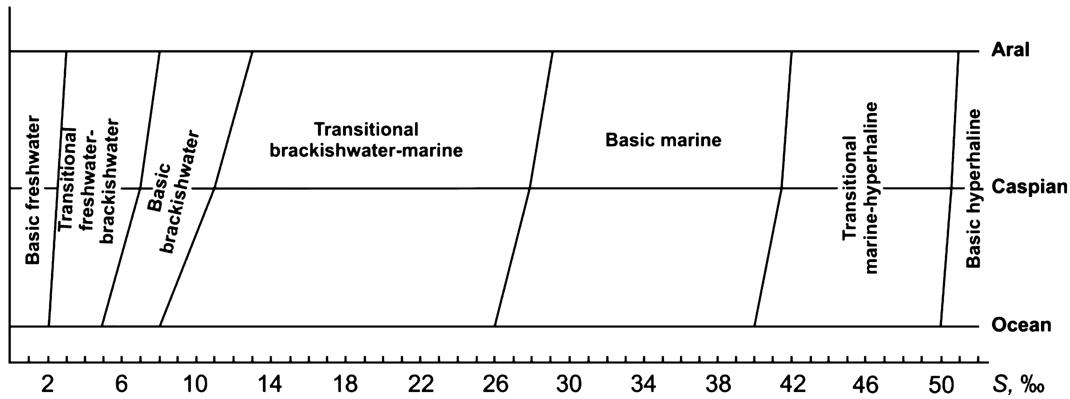

Fig. 4. Ranges of salinity zones.

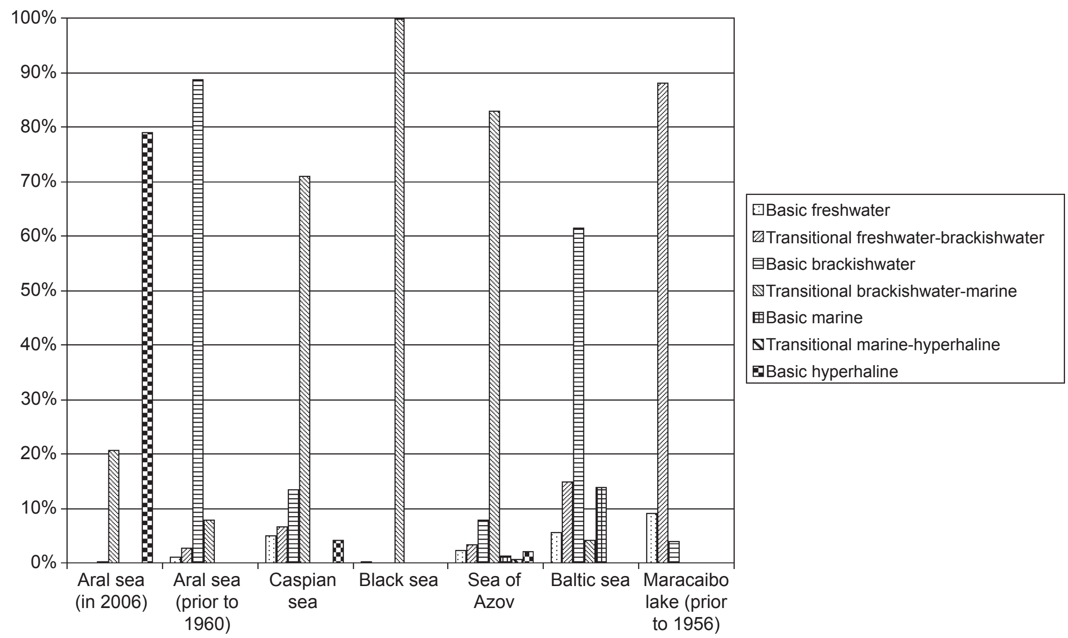

Fig. 5. Percentage of areas of different salinity zones in hybrid marine/lacustrine seas and saline lakes.

The receding sea has exposed and dried 54 000 km^2 of seabed, which is choked with salt and in some places laced with pesticides and other agricultural chemicals deposited by run-off from farms in the area. Strong windstorms blow salt, dust and contaminants as far as 500 km. Airborne sodium bicarbonate, sodium chloride and sodium sulphate kill or retard the growth of natural vegetation and crops (Micklin & Aladin 2008).

BALTIC SEA

The Baltic Sea is young and being a cold lake in glacial times. It still retains many features of a lake. It is a semi-closed, shallow, brackish waterbody with a smooth salinity gradient, and unique fauna and flora. The biodiversity of Baltic Sea is relatively low but is unique. Rivers play an important role in the water balance of the Baltic Sea.

There are oligohaline and mesohaline water zones in the Baltic Sea, each with its own specific flora and fauna. The areas with the most freshwater characteristics are the Gulf of Finland and Gulf of Bothnia. The central water zone of the Baltic Sea has a pronounced mesohaline character. Polyhaline conditions can only be found in Kattegat and Sound.

The biodiversity of this young sea was formed in postglacial times, with a highly heterogeneous composition. It consists of three main components: marine, fresh water and brackish water (*sensustricta*). The first group is the main portion of Baltic Sea biota. It includes relicts of previous geological times and immigrants from

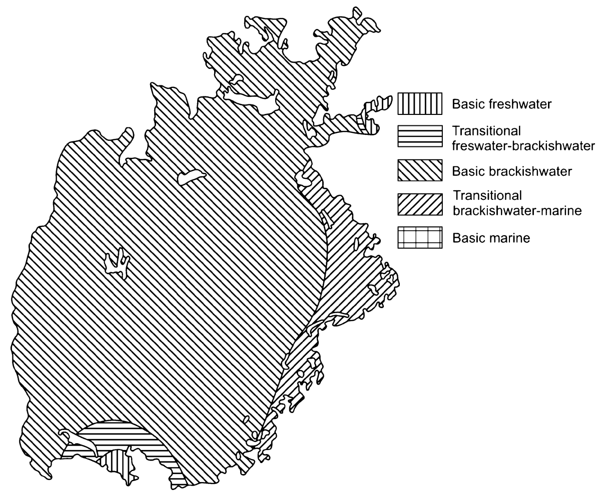

Fig. 6. Salinity zones of the Aral Sea in 1960.

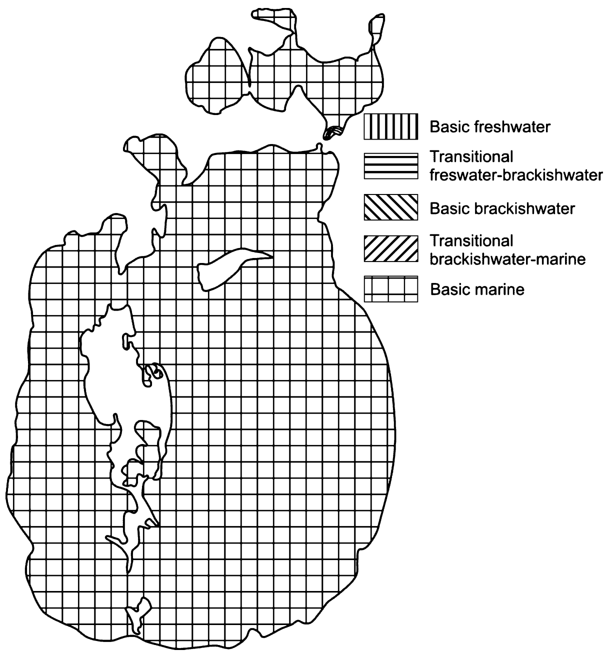

Fig. 7. Salinity zones of the Aral Sea in 1989.

remote marine waterbodies. The second group includes a large number of Baltic Sea inhabitants that arrived with the freshwater inflows. The third group is represented by a large number of species and is divided into two subgroups:

1. Ancient brackish water arctic relicts (pseudorelicts-immigrants) formed in glacial times in relatively fresher water areas of the arctic basin that migrated into the Baltic Sea in postglacial times from the northeast and east, possibly via fresh waters; and

2. Brackish water forms originated from freshwater forms.

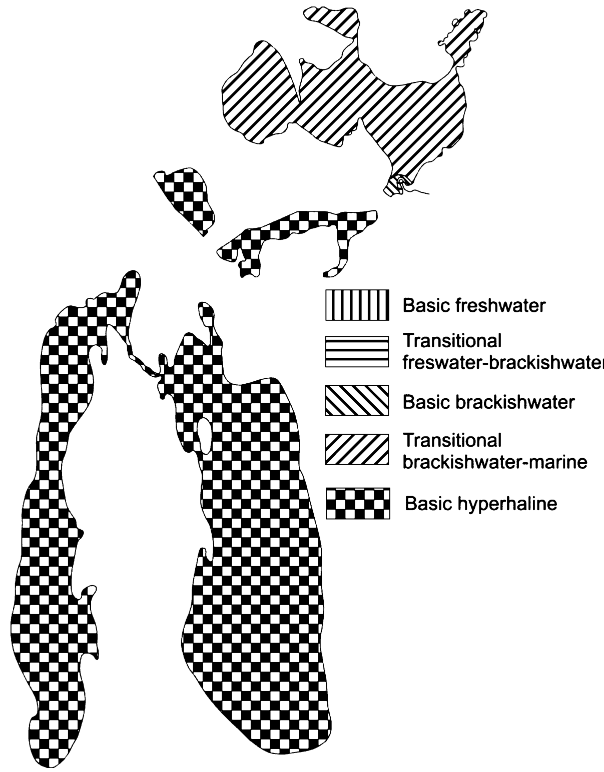

Fig. 8. Salinity zones of the Aral Sea in 2006.

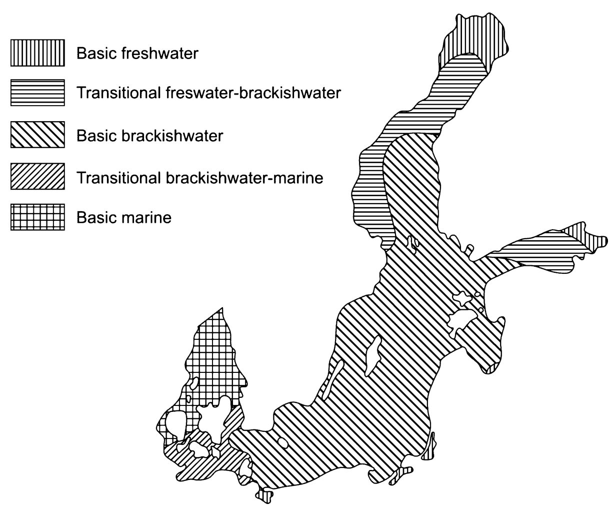

Fig. 9. Salinity zones of the Baltic Sea.

It is possible to distinguish all four basic and three intermediate zones in the Baltic Sea (Fig. 9). The basic zones are fresh water, brackish water, marine and hyperhaline. The intermediate zones are the following:

(i) transitional between fresh water and brackish water; (ii) transitional between brackish water and marine and (iii) transitional between marine and hyperhaline. Based on the earlier published concept of relativity and plurality of barrier salinity zones (Aladin 1988), the following bounds of these zones for the Baltic Sea are defined and discussed in the following section.

The freshwater zone in the Baltic Sea occupies inflowing rivermouths and also adjoining areas of shallow gulfs. The absence of pronounced high and low tides in the Baltic Sea contributes to a stable existence of δ-horohalinicum (0.5–2‰). This barrier salinity divides freshwater ecosystems from brackish water. δ-horohalinicum is well distinguished in the eastern part of the Gulf of Finland and the Northern part of the Gulf of Bothnia. Outstanding examples are the Vistula and Curonian lagoons, which are divided by this barrier salinity into fresh and brackish water zones. In the southeastern area of the Gulf of Riga, which is permanently influenced by river inflow, the δ-horohalinicum zone is also well distinguished. The area of the Baltic Sea occupied by fresh water is not large, being only 6% of the total area.

There are only small areas where fresh riverine waters mix with saline Baltic Seawaters. The salinity varies in this portion from fresh water up to 2‰. However, many freshwater plants and animals live only here never being observed in the Baltic Sea proper. There are about 1200 species of fishes, free-living invertebrates and plants (excluding bacteria, protozoans and tiny metazoans) in Baltic Sea freshwater ecosystems. These waters are shallow, with maximal depths not exceeding several tens of metres. Special characterization of freshwater zones and ecosystems is important to formulate a universal concept of Baltic Sea biodiversity. δ-horohalinicum constitutes a barrier that prevents freshwater organisms from invading the Baltic Sea.

The brackish-water zone and α-horohalinicum occupy the Baltic Sea proper, Bothnian Sea, Archipelago Sea and Gulf of Riga. This boundary zone occupies the largest part of the Baltic Sea (about 62% of the total). The salinity here varies between 5‰ and 8‰, with many scientists considering these salinities as the normal salinity of the Baltic Sea. In the Baltic Sea, α-horohalinicum is occupied by brackish water ecosystems, which exhibit the poorest species number. There are about 700 species of fish, free-living invertebrates and plants (excluding bacteria, protozoans and tiny metazoans) in this region. Some of them are descendants of inhabitants of a glacial lake in the Ice Age that existed where the modern sea is now located. Zone of α-horohalinicum occupies the deepest part of the Baltic Sea, with depths up to 500 m.

β-horohalinicum (22–26‰) is located in the western part of the Baltic Sea and in the eastern waters of the Danish Straits, which are strongly influenced by the influx of fully saline waters from the North Sea. The salinity here varies from 22‰ up to 26‰. Although this area is only about 4% of the total Baltic Sea area, the number of species of fishes, free-living invertebrates and plants (excluding bacteria, protozoans and tiny metazoans) is about 3000.

γ-horohalinicum (45–50‰) is not found in the main part of the Baltic Sea. In fact, this zone is outside the bounds of the Baltic Sea. γ-horohalinicum can be found in rock pools or on salted shoals called 'salt marshes'. Hyperhaline ecosystems can be named seasonal ecosystems, which are formed in summer when the evaporation is greatest. γ-horohalinicum separates inhabitants of fully saline Baltic Seawaters from inhabitants of hyperhaline waters, where the maximum number of plant and animal species (including unicellular ones) does not exceed 100.

The main threat to the Baltic Sea is eutrophication. This subject is well discussed in the Baltic Sea Action Plan. It is hoped that environmental mistakes made by agricultural enterprises around the Aral Sea will not be repeated in the area around the Baltic Sea.

SEA OF AZOV

The Sea of Azov is a semi-closed, shallow, saline waterbody with a smooth salinity gradient similar to that of the Baltic Sea. The Kerch strait connects it to the Black Sea. Only two large rivers, Don and Kuban, flow into the Sea of Azov. It is possible to distinguish all four basic and three intermediate salinity zones, in the Sea of Azov, which have the same bounds as seen in the Baltic Sea (Aladin *et al.* 2005).

There are freshwater zones in the Sea of Azov at the Don and Kuban rivermouths. The absence of pronounced high and low tides in the Sea of Azov contributes to the stable existence of δ-horohalinicum. This barrier salinity zone is well defined in the eastern part of Taganrog Gulf and at the mouth of the Kuban River. A brackish-water zone and α-horohalinicum occupy the Sea of Azov and the western part of Taganrog Gulf. The largest part of the Sea of Azov is occupied by a transitional brackish water-marine salinity zone (Fig. 10).

Other salinity zones and horohalinicums can only be found in the Sea of Azov in its shallow Sivash Bay. There is a pronounced salinity gradient in this bay, with the top water layer exhibiting hyperhaline conditions (Fig. 10).

CASPIAN SEA

The Caspian Sea, located between Europe and Asia, is the largest terminal lake on Earth. Although the Caspian Sea is a continental waterbody, it is of oceanic origin, being the remainder of Paratethys – a gulf of the ancient ocean Tethys. Its salinity is explained by its origin from this ancient ocean. About 6 Ma, the Pontic Lake was

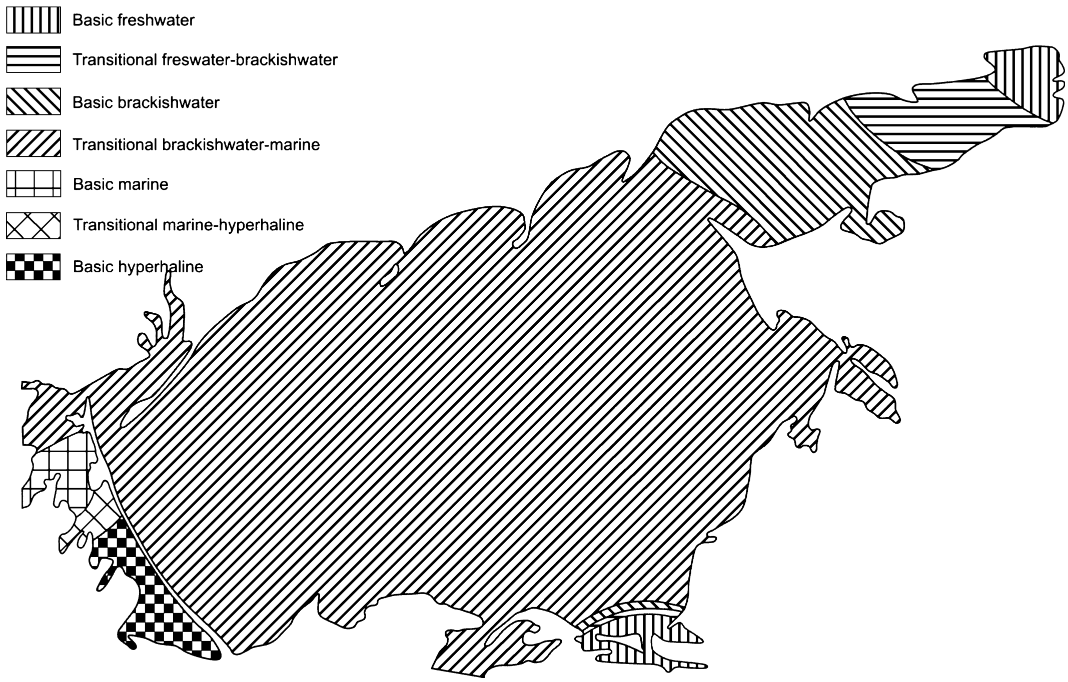

Fig. 10. Salinity zones of the Sea of Azov.

divided into Upper Pontic Lake occupying the Black Sea hollow and the completely isolated Babadjan Lake occupying only the South-Caspian hollow. The Caspian Sea has existed as an isolated basin since that time. The Caspian Sea has undergone a number of transgressions and regressions, accompanied by significant salinity decreases or increases. The modern Caspian Sea was formed about 5–7 thousand years ago (Aladin & Plotnikov 2000a).

The Caspian Sea occupies a vast, deep continental depression. Its modern level is around −27 to −28 m b.s.l. (Frolov 2003; Bolgov *et al.* 2007; Rumyantsev and Trapeznikov (2008). In terms of its morphology and physical-geographical conditions, the Caspian Sea is divided into the Northern, Middle and Southern Caspian Sea and the isolated Gulf Kara Bogaz Gol (Caspian Sea 1969, 1986). The middle and southern parts of the Caspian have the character of true seas, whereas the Northern part of the Caspian Sea is actually an extensive estuary of the rivers draining into it.

The maximum depth of the Caspian Sea is 1025 m, and its average depth is 208 m. The northern part of the Caspian Sea is shallow, with a maximum depth not exceeding 25 m and an average depth of 4 m (Nikolaeva 1971; Baidin & Kosarev 1986). Along the east coast, the shallow hyperhaline gulf-lagoon Kara Bogas Gol is connected to the main waterbody by a narrow strait (5.5–11 km long). Its water level is some metres below that of the Caspian Sea. There is a constant flow from the Caspian Sea to the gulf, with the water in it being quickly evaporated. In 1980, to slow down the decreasing Caspian Seawater level, the gulf was separated by a dam and for 3 years dried up almost completely, leaving a huge saline desert. The cessation of flows to Kara Bogaz Gol led to serious negative consequences. Salt began to be carried by winds, salinizing the surrounding environment and ground. The soil chemistry of gulf was also destroyed. A new channel to the gulf was constructed in 1984 and restored the flow, preserving the surface brines, decreasing the negative environmental impacts and allowing restoration of mineral salt extraction. As the Caspian Sea level began to increase, the dam was removed in 1992. The gulf is completely restored today.

Thirty rivers drain into the Caspian Sea, which has a catchment area of about 3.5 million km^2. The water balance of the Caspian Sea consists of river inflow, precipitation, evaporation and water outflow to Kara Bogaz Gol. The Volga River is the main influent water source for the Caspian Sea, providing almost 80% of its total inflow. The water income, however, is almost completely counterbalanced by evaporation, with the flow to Kara Bogaz Gol makes up only 5% of the inflow (Baidin & Kosarev 1986).

The water level of the Caspian Sea varies. Up to 1917, the level was relative stable. Between 1917 and 1925, the level fell from 25.82 m a.s.l. to −26.26 m. It increased slightly by 1930 up to 26.06 m a.s.l. This was followed by a slow water level decrease that subsequently accelerated after 1933. By 1941, the water level reached −27.88 m a.s.l. It again stabilized at −27.96 m a.s.l. The water level decrease began again in 1949, continuing to 1977, reaching a mark of −29.03 m a.s.l. However, a rapid water level rise began in 1978. It stabilized at −26.61 m a.s.l. in 1995. It has begun to slowly decrease since that time, lowering by 2002 to −27.15 m a.s.l. (Mihailov & Povalishnikova 1998; Mihailov *et al.* 1998). Changes in river inflow and visible evaporation are considered the principal cause of these Caspian Seawater level changes, although geological, climatic and anthropogenic factors are also considered important (Mihailov & Povalishnikova 1998; Frolov 2003; Bolgov *et al.* 2007). The rapid rise of the Caspian Seawater level has caused significant economic damage. There are significant territories in the flooding zone. Considerable quantities of polluting substances also entered the sea. Flooding of coastal oil extraction and transportation facilities has caused considerable harm to biodiversity. However, the water level increase also improved the feeding conditions for fishes, increased the area of spawning grounds, expanded the fresher water buffer zone and promoted increased potential productivity of the Northern Caspian Sea.

The average salinity of Caspian Seawater is 12.7–12.8‰. The maximum salinity (not including the gulf Kara Bogaz Gol) at the east coast is up to 13.2‰, whereas the minimum of 1–2‰ is observed in the northwest portion. Caspian Seawater has a rather low sodium and chlorine ion content, while it is richer in calcium, magnesium and sulphates ions because of the considerable period of isolation from the World Ocean, and from metamorphization under the influence of river inflows (Pahomova & Zatuchnaya 1966; Nikolaeva 1971).

The lowest salt concentration is observed in the Northern Caspian Sea, with an average of 5–10‰. Near the Volga, Ural and Terek deltas, the salinity is up to 2–4‰. In river avandeltas, the salinity is <0.5‰. In the shallow water areas of the east coast of the Northern Caspian Sea, the water salinity is above the average value. In its shallow gulf waters, the salinity can reach 30‰ and higher. The salinity of the Middle Caspian Sea is 12.7‰, while that of the Southern Caspian Sea is 13‰ (Zenkevich 1963; Nikolaeva 1971). The highest salinity is observed in the gulf Kara Bogaz Gol. It exhibits massive water evaporation, with the salinity of its waters being 300–350‰ and higher. The Caspian Seawater carries large salt loads into the gulf, with Kara Bogaz Gol playing the role of a water 'de-salter'. The evaporation and natural sedimentation have resulted in large accumulations of salt on the bottom of the gulf (Pahomova & Zatuchnaya 1966; Nikolaeva 1971).

There are all four basic and three intermediate salinity zones, and all barrier salinities having specific salt composition bounds in the Caspian Sea (Fig. 11). The freshwater zone in the Caspian Sea occupies a vast area around the delta of the Volga River in the Northern Caspian, and small areas at the other large rivermouths. A salinity gradient exists in this part of the sea, and there are transitional freshwater–brackish water and basic brackish-water salinity zones. The Middle and Southern Caspian Sea belong to transitional brackish water-marine salinity zone. Marine and transitional marine-hyperhaline salinity zones exist in the truncated salinity gradient in the entrance to the gulf Kara Bogaz Gol. The rest of the gulf is a hyperhaline zone.

The biodiversity of the Caspian Sea is about 2.5 times poorer than that observed in the Black Sea, and five times poorer than that in the Barents Sea (Zenkevich 1963). The salinity is too high for true freshwater fauna and flora, while it is too low for true marine species. By origin, its modern fauna is mainly of the Neogene Age. The recent biodiversity of the Caspian Sea reflects the complex history of Paleocaspian transgressions and regressions and is related to their freshening and salinization. More than 500 species of plants, and 854 species of fishes and animals of various origins, live in the Caspian Sea. Speciation in the Caspian Sea has created a generally high level of endemism (approximately 42–46%).

In the 20th Century, invasive species entered the Caspian Sea from other seas as a result of deliberate acclimatization of economic valuable fish species, as well as accidental input from ballast waters or from befouling on the bottoms of vessels. Such invasive species can seriously disrupt the biological balance that has developed in the ecosystem of this water body (Aladin & Plotnikov 2000b, 2004a,b; Aladin *et al.* 2002). The Caspian Sea fish stocks are estimated to be very large.

The ecological state of the Caspian Sea is now thought to be in a very complex condition. Rivers bring pollution to the Caspian Sea from its huge catchment area, which exhibits a strong anthropogenic influence. Its isolation also makes the Caspian Sea ecosystem (as a terminal lake) especially vulnerable to various kinds of pollutants generated within its basin. Thus, it accumulates all the harmful substances draining into it, with oil being probably the current major pollutant. In some areas, mainly where oil extraction and transportation takes place, the pollution can be catastrophic. Despite catastrophic local pollution, however, the waters of Caspian Sea as a whole are only lightly polluted, being attributed to a relatively rapid process of auto-purification (Aladin & Plotnikov 2000b). As a result of the

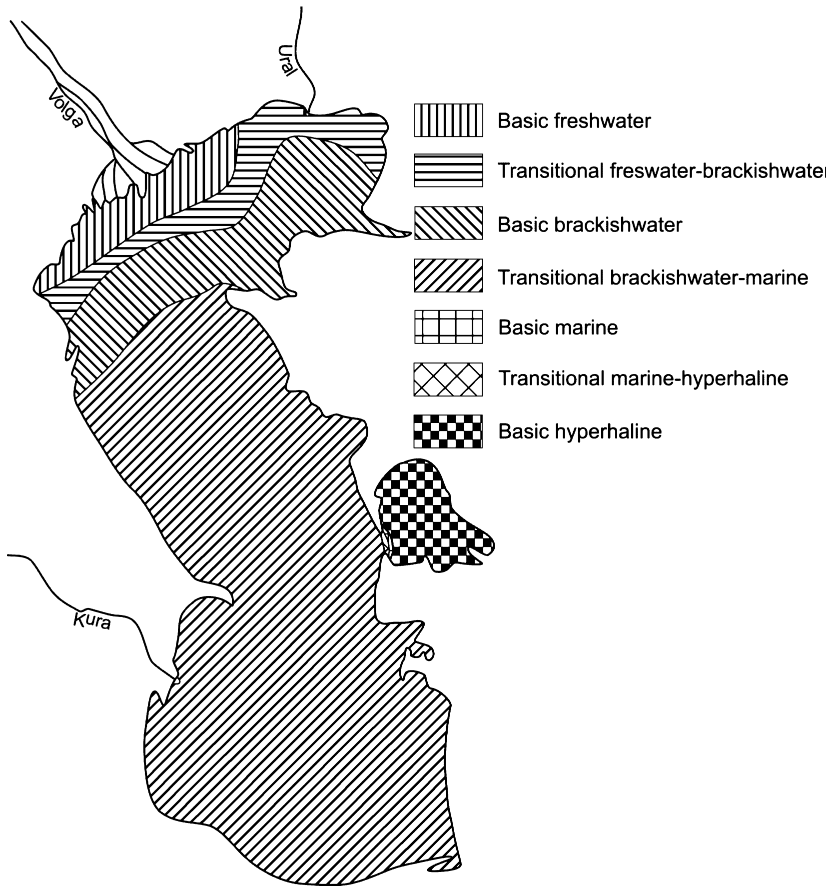

Fig. 11. Salinity zones of the Caspian Sea.

absence of a uniform agreement on protection of the sea among the riparian Caspian countries, a catastrophic increase in poaching has been occurring. Overharvesting of sturgeon has resulted in considerable difficulty in providing fish-breeding factories with the necessary number of spawners needed for their artificial cultivation and the reproduction needed to support their number. The continued existence of sturgeon in the Caspian Sea is clearly under threat (Aladin & Plotnikov 2000b).

LAKE BALKHASH

Lake Balkhash is a terminal lake in the desert part of eastern Kazakhstan. Its area varies in accordance with its water level, ranging between 17 000 and 22 000 km^2. The lake's east–west extent is 588–614 km, ranging from a 9–19 km width in its eastern section, and 74 km in its western section. Its maximum depth was 27 in the 1960s. The Ili River flowing to the western section contributes about 80% of the total annual inflow. Other rivers flow to the eastern part of the lake. The two sections of Lake Balkhash are relatively independent water systems, being connected by the shallow, narrow strait of Uzun-Aral. As a result of the lake's division into two sections of unequal size, with most inflow into the western side, the salinity in the west side of Lake Balkhash is very low (1.1‰), whereas it is higher in the east side of Lake Balkhash (4.3‰ or more). Mineralized waters of Lake Balkhash differ by ionic composition from marine waters in the Caspian and Aral Seas (Alekin 1984).

West Lake Balkhash is occupied by a freshwater salinity zone. East Balkhash belongs to transitional freshwater–brackish water salinity zone (Fig. 12). They are divided by δ-horohalinicum.

In the western part of Lake Balkhash, freshwater and euryhaline hydrobionts predominate. However, freshwater organisms disappear in the eastern Balkhash (Alekin 1984).

This study did not measure the organisms in this lake. The suggestions contained herein are based on the study data of the inhabitants of the Aral Sea. This same approach was applied to determine the salinity ranges. Considering studies of Khusainova and Karpevich, however, the possibility also exists that the salinity ranges could shift to higher salinities than observed in the Aral Sea.

An extension of irrigated areas began in 1967, and the Kapchagay Reservoir on Ili River began to fill in 1960. Water withdrawals increased, causing decreased water levels in Lake Balkhash, as well as some salinity increase. Continued water level declines can lead to complete degradation of the basin ecosystem, as observed for the Aral Sea basin (Abrosov 1963; Tarasov 1965).

Accepted recommendations have enabled some improvement in the lake's current siltation situation, as far as its biota are concerned, although river pollution and increased salinization continues.

LAKE MARACAIBO

The Maracaibo System is located in northwestern Venezuela. It consists of Lake Maracaibo and a natural channel, composed of Maracaibo Strait and Tablazo Bay, connecting the lake with the Gulf of Venezuela. The length of Lake Maracaibo from the north to the south is 150 km, and its greatest width reaches 120 km. With a surface area of 12 000 km^2, Lake Maracaibo has an average depth of 26 m and a maximum depth of 34 m. Thirty rivers flow into the lake, with its only outflow being via Maracaibo Strait. It is 40 km long and has an

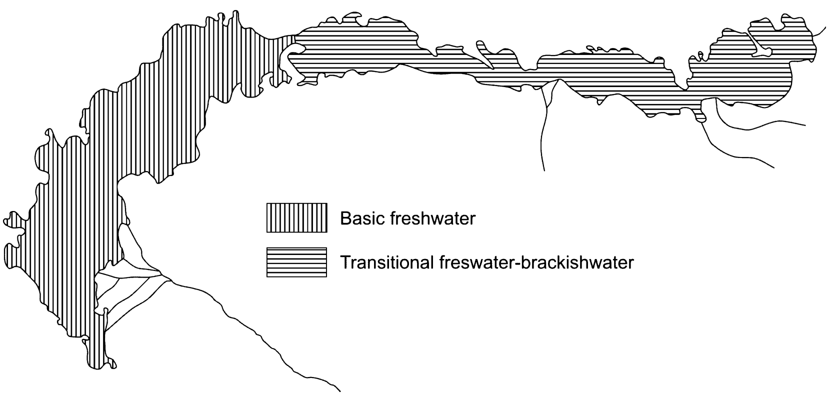

Fig. 12. Salinity zones of Balkhash Lake.

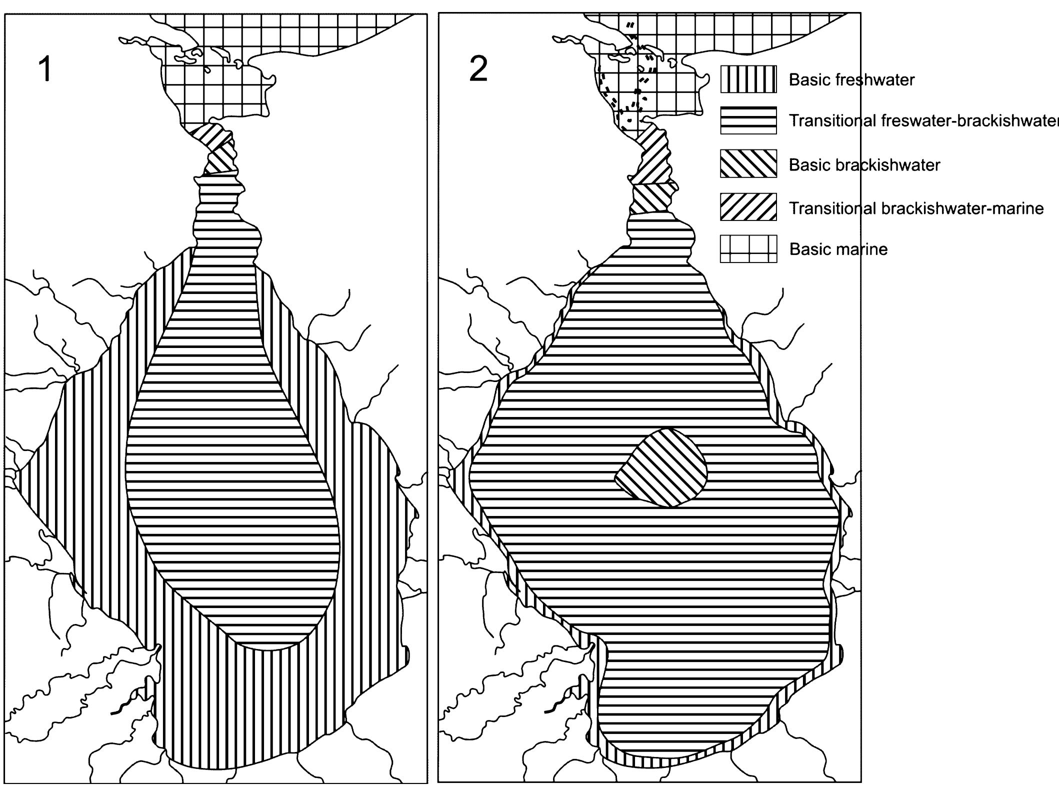

Fig. 13. Salinity zones of Lake Maracaibo.

average width of 7.7 km. It exhibits a salinity gradient. Shallow (mean depth 3 m) Tablazo Bay connects Maracaibo Strait and the Gulf of Venezuela. Its connection to the Gulf of Venezuela is restricted to two small openings between islands (Parra-Pardi 1983; Bautista *et al.* 1997; Laval *et al.* 2003, 2005).

This natural channel was deepened by a 14 m deep, 100 km long, dredged shipping lane in 1956, causing increased intrusion of seawater from the Gulf of Venezuela into Lake Maracaibo. Prior to 1956, diluted seawater entered Lake Maracaibo during the dry season. During the wet season, the restriction of Tablazo Bay and Zapara Mouth was sufficient to prevent the influx of diluted seawater into the lake (Laval *et al.* 2003, 2005). The salinity in Lake Maracaibo was low, with only basic fresh water and transitional fresh water–brackish water observed in the lake zones (Fig. 13). Thus, only δ-horohalinicum can be found in this waterbody. The saline water inflows from the Gulf of Venezuela after 1956 has resulted in persistent salinity stratification in Lake Maracaibo (Laval *et al.* 2003, 2005) and increased total salinity and the appearance of a brackish water salinity zone (Fig. 13) and α-horohalinicum.

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