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Large saline lakes of former USSR: a summary review

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Abstract

Seven of the largest lakes in central Asia (former USSR) are saline: Caspian Sea, Aral Sea, lakes Balkhash, Issyk-Kul, the Chany complex, Alakul and Tengiz. They range in salinity from sometimes $<3\ g\ l^{-1}$ to $19\ g\ l^{-1}$. The paper provides a summary review of their major physico-chemical and biological features. Several are threatened by activities in their drainage basins, particularly diversion of inflowing waters.

Introduction

There are more than 2 800 000 lakes in the CIS (former USSR), with a total surface area of nearly 980 000 km^2. Most (99.2 per cent) are small and shallow, with an area of less than 1 km^2, but sixteen are amongst the world's largest lakes, each with an area in excess of 1000 km^2. Of these very large lakes, seven are saline: the Caspian and Aral seas, and lakes Balkhash, Issyk-Kul, Chany, Alakul and Tengiz. The total surface area of these saline lakes is nearly 523 000 km^2, *i.e.* more than half (53.4 per cent) of the total lacustrine area in the CIS. Table 1 gives their main characteristics at the highest recorded water-levels.

Rather little information on these important lakes is freely available outside the CIS. The present paper aims to introduce these lakes by means of a summary review of their major limnological features.

Caspian Sea

The Caspian Sea is the largest body of inland water in the world. Situated in the CIS and Iran, this endorheic lake stretches north-south some 1200 km, and has a mean width of 320 km. The length of its shoreline is nearly 7000 km. Its present (1991) area is 371 000 km^2, and present elevation ± 28.5 m below sea-level. Maximum

Table 1. Major physico-chemical features of the largest salt lakes in the CIS. Values for each lake are for the time during the 20th century when it had its highest water level.

Lake	Area (km^2)	Volume (km^3)	Elevation above sea level (m)	Max. depth (m)	Salinity ($g\ l^{-1}$)
Caspian	422 000	79 000	−26	1072	10–12
Aral	66 100	1 064	53	69	8–10
Balkhash	22 000	122	343	27	0.5–7
Issyk-Kul	6 280	1 730	1608	702	5–6
Chany	3 245	7.1	106	10	1.5–4
Alakul	2 650	N.A.	343	45	5–7
Tengiz	1 590	N.A.	304	8	3–19

N.A. not available.

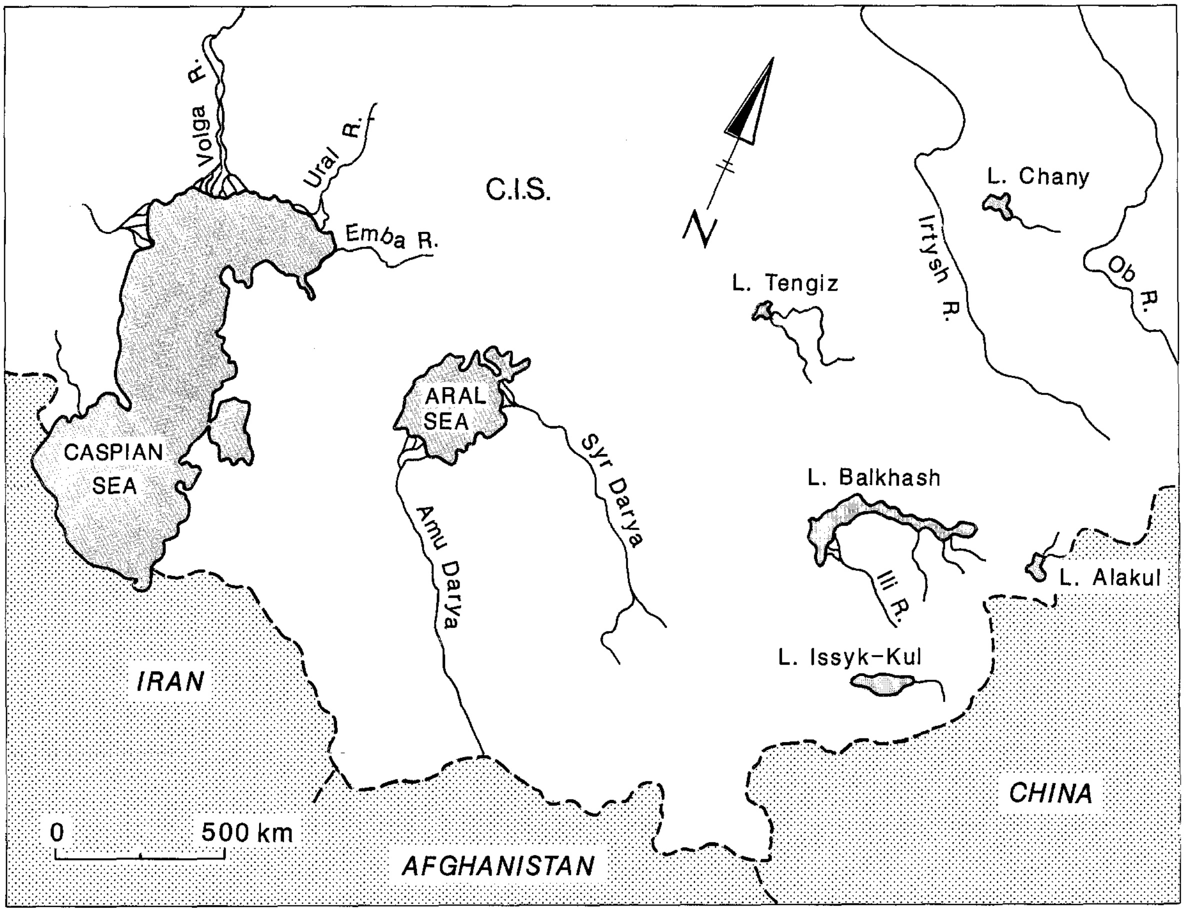

Fig. 1. Location of lakes discussed in the text.

depth is 1025 m. Since 1929, its depth has decreased because of a decrease in the supply of inflow waters resulting from the building of hydroelectric power stations on the Volga. By 1969, its level had fallen some 2.5 m, and its area had diminished by 51 000 km^2.

The largest embayments of the Caspian Sea are: Kizlyarskiy and Komsomolets in the north, Mangyshlakskiy, Kenderly, Kazakhski, Kara-Bogaz-Gol and Krasnovodskiy in the east, and Agrakhanskiy and Bakinskiy in the west. There are fifty islands with a total surface area of 350 km^2, the largest being Kulaly, Tyuleniy, Chechen', Artem, Zhiloy and Ogurchinskiy islands. Morphometrically, the lake can be divided into a northern, middle and southern part. Into the northern part flow the Volga, Embra, Ural and Terk rivers; these contribute 88 per cent of the total annual river inflow. On the west coast the rivers Sulak, Samur and Kura give 7 per cent of the total inflows. The remaining inflows (5 per cent) are provided by rivers from Iran. There are no regular streams on the east coast.

Moderate and high winds are frequent so that a large number of days has significantly rough water. In summer, the average temperature of surface waters is 24–26 °C, but in the south it reaches 29 °C, and in Krasnovodskiy Gulf, 32 °C. On the east shore, the upwelling of cold water from the deeper parts of the lake often results in temperatures as low as 10–12 °C in June and August. In winter, the temperatures are quite different: in the north, water temperature is −0.5 °C, but in the middle it is 8–10 °C. The northern Caspian Sea is covered with ice for 2–3 months.

Average salinity is 12.7 to 12.8 g l^{-1}. Maximum values are recorded in the east – up to 13.2 g l^{-1}g. Minimum values occur in the north – to 1–2 g l^{-1} – and reflect the freshening effect of the Volga inflow.

The flora and fauna of the Caspian is rather small. However, significant biomass is present. Even so, there are $\pm$500 plant species, and at least 629 invertebrate and 78 fish species. Species have been introduced either intentionally or accidentally (Karpevich, 1975; Zenkevich, 1963).

The Caspian has long been an important fishery where many valuable species are caught. Thus, it provides 82 per cent of the world catch of sturgeons. However, because the water-level has fallen and because of river flow regulation, many spawning grounds have disappeared, and habitats for reproduction of migrating fish decreased. This, in turn, has caused a decrease in the fish catch (Zenkevich, 1963).

At present, the water-level has stopped falling and has even increased slightly. However, water pollution is becoming more intense especially because of increasing pollution from the Volga River. As a result, the existence of sturgeons is endangered; for example, the toxic effect of pollution gives rise to different pathologies, including lamination of muscles.

Aral Sea

The Aral Sea, formerly the second largest lake in the CIS in area, is now rapidly decreasing in size. In the past thirty years, its water-level has dropped 15 m, its salinity has increased from 8–10 g l^{-1} to 30 g l^{-1}, and its volume has decreased by more than 60 per cent. The desiccation is the result of reduced inflows caused primarily by water diversions for irrigation from two large inflowing rivers, the Syrdarya and Amudarya. From the middle of the nineteenth century until 1960–1962, the average salinity was 8–10 g l^{-1}. During that time, most of the biota was of freshwater origin and was only able to regulate hyperosmotically. In 1974–1976, however, the average salinity of the Aral increased by more than 14 g l^{-1} and most species of freshwater origin became extinct. From 1974–1976 to 1985–1987, *i.e.* when the average salinity was <24 g l^{-1}, most species were of brackish water origin and were osmoconformers or hypoosmotic regulators. In 1985–1987, when the average salinity increased to >24 g l^{-1}, nearly all of these populations also became extinct. At present, the average salinity is 28–30 g l^{-1}, and most species are of marine origin and are either osmoconformers or hypoosmotic regulators. In the future, when average salinity will exceed 42–44 g l^{-1}, nearly all of these marine species also will become extinct, and the only inhabitants will be hypoosmotically regulating species typical of hypersaline water-bodies.

Principal sources of information on this lake are: Williams & Aladin, 1991; Aladin & Potts, 1992.

Lake Balkhash

Lake Balkhash (*Ak-Dengiz* in Kazakh) is a terminal lake in eastern Kazakhstan, located in the Balkhash-Alakol desert at an altitude of 343 m above sea level. Its area varies with its water level and is 17 000–22 000 km^2. The lake extends east-west by *ca* 588–614 km, and is from 9–19 km wide in its eastern section and 74 km wide in its western section. In the 1960s, maximum depth was 26.5–27.0 m, and the volume was 122 km^3. Volume was 111.5 km^3 in the 1920s. Northern shores are high and rocky; southern ones are low-lying, sandy, and fringed by dense reeds and swamp. Climate in the region is arid, sharply contintental, and annual evaporation over the lake is 950–1200 mm and annual precipitation is 150 mm. The Balkhash catchment has an area of 500 000 km^2 and contains $>52\,600$ km of rivers and streams, the largest of which are the rivers entering the western part and the rivers Karatal, Lepsy, Aksu and Ayaguz entering the eastern part. The River Ili contributes some 78 per cent of total annual inflow to the lake, which averages 15.6 km^3 (Anon, 1984; Domrachev, 1933).

According to A. A. Tursunov (personal communication, 1991), the water balance of Balkhash under natural conditions (*i.e.* before 1970) was maintained by mountain rivers with a discharge of 23.8 km^3 per year. Most of this, 17.4 km^3 per year, was provided by the River Ili, and the rest, 6.4 km^3 per year, by the eastern rivers (Karatal, Aksu, Lepsy, Ayaguz), all except the last flowing from Dzungaria Ala-Tau. However, only 14.9 km^3 of the annual discharge actually reached Lake Balkhash where it completely evaporated; the rest, 8.9 km^3, was expended in the basin to maintain marshes of the unique delta of the River Ili (Domrachev, 1940; Tarasov, 1965), tugays along the river, and small irrigated areas in the basins of the River Ili (Domrachev, 1940; Kipshakbaev *et al.*, 1985) and eastern rivers (3.2 km^3 per year).

In 1967, an extension of irrigated areas began, and in 1970 the Kapchagay Reservoir, the largest reservoir in the region, began to fill. As a result, water withdrawal from the river basin increased sharply, and from about 1974 a new regressive period began which caused a sharp decrease in the level of Lake Balkhash and intensified earlier anthropogenic pressures on the lake ecosystem and the River Ili (Tarasov, 1965; Abrosov, 1963).

Since 1970, the basin's water resources have also decreased to 22.4 km^3 per year due to natural climate aridity. This resulted in the flow of the River Ili decreasing to 16 km^3. Water losses have also increased, including losses for filling and maintaining Kapchagay Reservoir, for irrigation, and for other reasons. As a result, the level of Balkhash fell sharply. Relative increases in the amounts of water during the period 1979–1981 did not reverse the trend and by the beginning of 1983 the level of the lake was at *ca* 341.0 m, its historical minimum. Continued falls in its level will lead to the complete degradation of the basin ecosystem, as has happened in the Aral Sea basin (Kipshakbaev *et al.*, 1985; Tursunov *et al.*, 1986).

Further events have completely confirmed predictions. Moreover, aridity in the basin has intensified. Thus, by the end of 1986, the level of Balkhash had decreased to 340.5 m. Acceptance of scientific recommendations, however, has led to some stability in the level of the lake at its 100 year minimum, and preparation for the times when full-flowing rivers would ensure increased inputs. This occurred in 1988 when inflows into Kapchagay Reservoir were >20 km^3 (the 100 year maximum [1960] was 22.7 km^3, and the annual mean is 14.7 km^3). In summary, conservation measures precluded any further filling of Kapchagay Reservoir. In 1988, inputs into Balkhash from the eastern rivers were nearly 50 km^3, and from all sources were >194 km^3. Of these inputs, *ca* 12 km^3 evaporated (mean evaporation, 15 km^3), but the volume in the lake increased by 7.0 km^3 and the level by nearly 100 cm.

Thus it appears that Lake Balkhash and the Ili-Balkhash basin are not now threatened: the lake level is significantly above the minimum, the terrestrial environment and the River Ili have improved ecologically, and the most serious forms of human pressure (Kapchagay Reservoir, irrigation) have eased. This should enable the maintenance of the lake's water level at 341 m. Even so, it would be unwise to assume that the threat has gone. The recommendations accepted enabled some improvement in the position of the lake so far as its biota was concerned, but river pollution continues, salinization proceeds, and the concentration of certain toxic substances such as nitrates, pesticides, heavy metals (copper, zinc and cadmium) and carcinogenic substances increases.

Lake Balkhash is divided into two relatively independent sections: a wide and shallow western section, stretching from south-west to northeast, and a deep (to 27 m) and narrow eastern section, stretching from west to east. These sections are connected by the Strait of Uzun-Aral, a narrow (3.8–4.2 km), shallow (maximum depth 2.8–3.3 m) channel. Because of the lake's division into two sections of unequal size, with most inflow into the western section, salinity in west Balkhash is very low (1.1 g l^{-1}), whereas in east Balkhash, salinity is much higher (4.3 g l^{-1}). Water transparency is 5.5 m. Surface temperatures fall to 0 °C in December, but reach 28 °C in June. Differences in summer between surface and hypolimnetic temperatures are <3.3 °C. Generally, aerobic conditions prevail, but an oxygen deficiency sometimes develops in vegetated shallow areas. Bottom sediments are mainly silty, but peat and balkhashite also occur.

An increase in lake salinity has also been observed, resulting not only from changes in the hydrological balance, but also from a rise in the salinity of the River Ili (from 0.25–0.37 to 0.42 g l^{-1}) after the regulation of its flow. By 1978, the salinity of Balkhash had increased from 1.12–4.31 to 1.42–5.14 g l^{-1}.

Ionic composition is distinctive. The proportion of chloride (9–21 equiv. percent) is 2–3 times lower than the proportion of chloride in the sea. However, the proportions of potassium, calcium, magnesium, sulphate and carbonate/bicarbonate ions are significantly higher. In eastern Balkhash, the proportion of potassium ions (2.9 equiv. percent) is very high in comparison to other waters (e.g. 0.6 equiv. percent in the ocean and the Aral Sea). The lower proportion of calcium ions, especially in comparison with the Aral and Caspian seas, also is notable (Anon., 1984; Panov, 1933).

Two hundred and six species of algae have been recorded. Half are diatoms, and 67 per cent are planktonic. The benthic algae are predominantly diatoms. Most algae in Balkhash are freshwater forms (oligohalobionts) or euryhaline forms (77 per cent), but there are a few halophiles (9 per cent), halobionts (4 per cent) and mesohalobionts (10 per cent) (Karpevich, 1975; Anon., 1984). Cryophilous diatoms predominate in spring and autumn, but with increasing temperatures green algae develop. Cyanobacteria predominate in summer. In spring, phytoplankton biomass is 1 g m^{-3} and in summer up to 47 g m^{-3}. In autumn, it decreases to 0.6 g m^{-3}. The least saline western part of the lake has the most dense zooplankton (annual average value, 3.5 g m^{-3}), whereas in the more saline eastern part the average is significantly lower (0.6 g m^{-3}). A regular change in zooplankton species composition occurs from west to east. In the western part, freshwater and euryhaline forms predominate, but freshwater forms disappear eastwards and are replaced by halophiles and mesohalobionts. Because of the increased salinity, some halophiles have now spread from the east to the west. By the end of the 1970s, the average phytoplankton biomass in western Balkhash had decreased by more than 50 percent, possibly because of the increased salinity. Freshwater species are rarer and their place has been taken by saline forms (Anon., 1984).

Zooplankton has consisted of 54 species: 5 protozoans; 28 rotifers (the most common being *Filinia* (= *Triarthra*) *longiseta* (Ehrenb.), *Polyarthra platyptera* Ehrb, *Pompholyx sulcata* Hud., *Keratella* (= *Anuraea*) *cochlearis* (Gosse), *Pedalion oxyuris* (Zernov); 11–18 cladocerans (the most common being *Diaphanosoma brachyurum* Lievin and *Daphnia cristata* (Sars) (= *Cephaloxus cristatus*); 8–11 copepods (the most common being *Thermocyclops crassus* (Fischer), *Mesocyclops leuckarti* (Claus), and *Arctodiaptomus* (= *Diaptomus*) *salinus* (Daday)) (Rylov, 1933; Karpevich, 1975). In the zooplankton, *A. salinus* and *D. brachyurum* comprised 60–70 per cent of the biomass. In the more saline eastern Balkhash, the predominant forms were *A. salinus*, *Polyphemus pediculus* (L.) and *Sida crystallina* (Muller) (Saduakasova, 1972). In the 1970s, zooplankton biomass attained 1 g m^{-3} (Anon., 1984).

The recent zoobenthic fauna of Balkhash basically consists of introduced species. In the 1950s and 1960s, some species were introduced successfully from the Caspian Sea and the Sea of Azov. They included the Caspian polychaete worms *Hypania invalida* (Grube) and *Hypaniolla kowalevskyii* (Grimm), the mysids *Paramysis lacustris* (Czern), *P. intermedia* (Czern), *P. ullskyi* (Czern), and *P. baeri* (Czern), the amphipod *Corophium curvispinum* Sars, the mollusc *Hypanis colorata* (Eichw.) (= *Monodacna colorata*), as well as the accidently introduced molluscs *Dreissena polymorpha* (Pall.), *Anodonta cygnea* (L.), and *A. cellensis* (Schroter) from the River Ural. These introduced forms are now predominant in the zoobenthos (Karpevich, 1975).

The composition of the zoobenthos is different in the eastern and western parts of the lake. In the less saline western part, the biomass is highest (mean of 4.2 g m^{-2}), and the main species are the oligochaetes *Tubifex tubifex* (Muller), *Nais pardalis* Piquet and *Stylaria lacustris* (L.), the mollusc *H. colorata*, the mysids *P. intermedia*, *P. lacustris* and *P. baeri*, and the amphipod *C. curvispinum*.

In eastern Balkhash, on the other hand, the zoobenthos biomass is lower 1.4–2.1 g m^{-2}), and there are no polychaetes or amphipods. Also absent is *H. colorata*, but the endemic mollusc *Bithynia caerulans* West. occurs. As one moves eastward, mysids disappear in the order *P. baeri*, *P. lacustris*, *P. ullskyi*, and, last, *P. intermedia*; and not even the last species is found in the eastern end of the lake. The dominant components of the zoobenthos in the east are chironomids, oligochaetes, and molluscs. The main chironomid taxa under conditions of increased salinity are *Chironomus salinarius* Kieff. and *Procladius* sp. (Anon., 1984; Mikulin, 1933).

Of special note, so far as the biota is concerned, is the unfavourable ionic composition of Balkhash water (high concentrations of potassium and magnesium; Karpevich, 1975) compared to other large saline contintental water bodies. Thus, any increase in salinity quickly affects its biota and causes a major reduction in biomass.

There is a valuable fishery in Lake Balkhash, with 21 species of fish present. The original fish fauna, however, consisted of only 4 species in the lake itself: the Balkhash marinka (*Schizothorax argentatus* Kessler), the Ili marinka (*S. pseudaksaiensis* Hen.), the Balkhash perch (*Perca schrenki* Kessler), and the spotted stone loach (*Nemachilus strauchi* (Kessler)). Other fish inhabited the deltas of the rivers. In the lake, representatives of the high-Asian fauna predominate. From 1930 to the 1960s, a series of introductions was made. Of these, several have become the principal species of the fishery and provide up to 99–100 per cent of the total catch: bream (*Abramis brama orientalis* Berg), roach (*Rutilus rutilus caspicus* Berg), carp (*Cyprinus carpio* L.), sander (*Lucioperca lucioperca* L.), wels (*Silurus glanis* L.), and asp (*Aspius aspius* (L.)).

Fish introductions have increased fish productivity by 20–30 per cent: In the 1960s and 1970s, the catches were 6700–16 500 tons per year (Karpevich, 1975; Anon., 1984). However, the fall in water level and the progressive increase in salinity have diminished the suitability of conditions for the reproduction of most fish present (Anon, 1984).

Presently, there is a project to maintain the hydrological regime in western Balkhash by separating it from eastern Balkhash by a dam and sluice in the Uzun-Aral Strait. In this way, the water supply to eastern Balkhash will be limited. In other words, it is proposed to sacrifice the eastern part of this unique water body which will become a shallow hypersaline lake (Anon., 1984).

Issyk-Kul

Issyk-Kul is a terminal, endorheic, mountain lake. Situated in north-eastern Kirghizia, it is located in the mountains of the northern Tien Shan between the ranges Kungey-Alatau to the north and Terskey-Alatau to the south. Its elevation is 1608 m above sea level. Major morphometric parameters are: area, ± 6236 km^2; length 178 km; width, 60 km; maximum depth, 668 m; average depth, 278 m; and volume, 1738 km^3. More than 50 rivers discharge into the lake, with a total annual discharge of > 3 km^3. The largest are the Dzhergalan and Tyup rivers, which flow into the eastern part of the lake. Rivers are snow-fed. Water from underground sources is of great significance (40 per cent of inflow, according to some) in the hydrological budget of Issyk-Kul.

Like all endorheic lakes, the water-level fluctuates. In the 17 and 18th centuries, the water level was 10–12 m higher than it is at present, and an outflow from the western part of the lake into the River Chu existed. Conversely, a thousand years ago the waterlevel was lower than the present one. Evidence for the considerable amplutude of Issyk-Kul transgressions and regressions during climate changes is given by the presence of ancient lake terraces of 8–10 m height, and by ruins of submerged settlements at a depth of 8 m. During the past two centuries, the level of Issyk-Kul has decreased, and since 1886 it has fallen by 4 m (7 m according to some sources) (Anon., 1984).

The regional climate is warm, temperate and dry. Average annual precipitation is 250 mm, but annual evaporation from the lake surface is nearly 700 mm. Surface water temperatures in January are not less than 2–3 °C, and in July extend to 19–20 °C. At depths of more than 100 m, the water temperature remains stable all year at 3.5–4.0 °C. The lake is not covered with ice in winter, but in cold winters ice can appear in some bays.

Water colour is blue, and transparency, > 12 m. The salinity at present is 6 g l^{-1}, but in 1930 it was 5.8 g l^{-1}. It cannot be used for drinking or irrigation. Compared to sea-water, sulphate concentrations are higher (44 equiv. per cent), chlorides are lower (45 equiv. per cent), and there is more magnesium, calcium and (bi)carbonate but less sodium and potassium (68.5 equiv. per cent). Issyk-Kul can be regarded as a mesohaline sodium-sulphate-chloride water-body.

Because of a general regional tendency towards decreased humidity and increased water withdrawals, the fall in the water-level of the lake level will accelerate. However, the large lake volume will prevent any rapid increase in salinity.

Bottom sediments are argillaceous silts, with narrow marginal strips of sand.

The lake is oligotrophic. The concentration of dissolved organic matter is low: permanganate oxidation in central regions may reach 2.7 mg O_2 l^{-1}. Oxygen concentrations are always high (7.1 mg l^{-1} or more), and a phytoplankton photosynthetic rate of 171 mg C m^{-2} d^{-1} has been recorded (Anon., 1984).

The phytoplankton consists of 299 species, of which 149 are diatom species in the nannoplankton, cyanobacteria and green algae predominate. There are many periphytic diatoms. Two seasonal peaks of phytoplankton abundance occur: May and October–November, minimum abundance is in January–February. Phytoplankton biomass in open parts of the lake is up to 211 mg m^{-3}, but in the bays it is higher (up to 1.7–5.3 g m^{-3}). Maximum numerical and biomass densities occur at 15 to 60 m.

Angiosperms occur down to 2 m, and charophytes are also present. The latter form an unbroken carpet down to depths of 30–40 m, and dominate the aquatic plant communities of the lake. The highest production of charophytes occurs at depths from 15 to 20 m. Charophyte biomass can reach 60 g m^{-2}. Of the angiosperms, *Phragmites communis* Trin. is most important but various species of *Potamogeton* are widespread. Annual macrophyte production is estimated at 1.72×10^6 tons (Anon., 1984).

There are 154 species recorded from the zooplankton: 76 protozoans, 78 rotifers, 11 cladocerans, and 8 copepods (Anon. 1984; Foliyan, 1973). Only 15 species occur in large numbers, namely, 9 species of rotifer (*Eosphora ehrenbergi* Weber, *Synchaeta cecilia* Rouss., *S. gyrina* Hood, *Euchlanis oropha* Gosse, *Brachionus quadridentatus* Herm., *B. urceus* (L.), *Keratella quadrata* (Muller), *Hexarthra oxyuris* (Zernov), and *H. fennica* (Lev.); two species of cladocerans (*Alona rectangula* Sars, *Alonella nana* (Baird)), and one species of copepod (*Arctodiaptomus salinus* (Daday)). *A. salinus* is the dominant member of the zooplankton but has a low productivity (production: biomass = 1.7). On the whole, the zooplankton biomass is low, with the annual average value ± 20 mg m^{-3}, and the maximum value up to 163 mg m^{-3} (Anon., 1984).

The zoobenthos has 176 species: 35 protozoans, 33 annelids, 20 crustaceans, 84 non-crustacean arthropods, and 4 molluscs. It is reasonably uniform down to 30–35 m, but at deeper levels it sharply declines in abundance. The dominant forms are chironomid larvae, molluscs, amphipods and mysids. These comprise up to 80–90 per cent of the biomass. The most numerous are 9 chironomid species: *Chironomus plumosus* L., *C. anthracinus* Zett., *C. cineulatus* Mg., *C. tentans* F., *Glyptotendipes gripecoveni* Kieff., *G. barbipes* Ean., *Stictochironomus pictulus* M., *Tanytarsus* sp., and *Cricotopus bicinctus* Meig. The mollusc *Radix auriculata obliquata* (M.) is widespread down to 60 m. Also widespread are the amphipods *Gammarus negri* M. and *G. ocellatus* M.. In summer the benthic biomass in the bays is 5–14 g m^{-2} (in some localities it reaches 20 g m^{-2}). Below the charophyte zone, zoobenthic biomass falls from 8.0–10.0 g m^{-2} to 2.5–3.5 g m^{-2} at depths of 60–70 m. In the profundal region, *i.e.* most of the lake bottom, zoobenthic biomass is < 0.2–0.3 g m^{-2}. Here, only the endemic oligochaetes *Enchytraeus przewalskii* Hrabe and *E. issykulensis* Hrabe and the amphipod *Issykogammarus hamatus* Chev. occur. In the 1960s, the mysids *Paramy-*

sis kowalevskyi (= *P. lacustris*), *P. baeri* and *P. intermedia* were introduced from Lake Balkhash. These spread during the 1970s over shallow areas, particularly in bays and fresher localities near rivers inflows. Their biomass reaches 1.5–2.5 $g\,m^{-2}$.

The fish fauna is represented by 27 taxa in five families. The long isolation of the lake has resulted in the development of several endemic species: Schmidt's dace (*Leuciscus schmidti* (Herz.), Issyk-Kul dace (*L. bergi*), gudgeon (*Gobio gobio latus*), Issyk-Kul marinka (*Schizothorax issykkuli* Berg), spotted stone loachs (*Nemachilus strauchi ulacholicus* Anikin, and *N. strauchi dorsaloides*), and the scaleless osman (*Dyptychus dybovskii* Kessler). In all, there were twelve original species. Since the 1930s, additional species have been introduced. The first to be introduced was the Sevan trout (*Salmo ischan gegarkuni* Kessler); this was followed by the introduction of the Aral bream (*Abramis brama aralensis* Berg), carp (*Cyprinus carpio*), and the sander (*Lucioperca lucioperca*). The commercial fish catch is from 250 to 400 tons per year. The main fish in this catch are daces, sander and trout (Anon., 1984).

Finally, in the bays of Issyk-Kul nearly 20 000–50 000 individual water birds over winter. To protect them, a reserve was established in 1958. This also protects pheasants and the mountain fauna of Kirghizia. The muskrat *Ondatra zibethicus* was introduced in 1944 and has spread in some localities along the shores in marsh vegetation.

Lake Chany complex

The Lake Chany complex, located in the Novosibirsk region between the rivers Ob and Irtish, lies in the Barabinsk steppe at an elevation of 106 m above sea-level. Its area fluctuates according to water-level changes but is between 1990 and 3245 km^2. The average depth is 2.2 m and the maximum, 10 m (presently 8.5 m). Depths of less than 3 m comprise 30 per cent of the total area, and depths of less than 2 m, 80 per cent. The lake complex is 82 km long, 36 km wide, and is characterised by a very indented shore line with many gulfs, bays, peninsulas and islands. Essentially it consists of a large Lake Chany (consisting of four sectors and Lake Yarkul) and a small lake Chany. One section of the larger lake is now isolated by a dam. The endorheic catchment area is 29 935 km^2. Inflow from rivers is small, and the main ones are the rivers Chulym and Kargat. These are mainly (91 per cent) supplied by snowmelt.

Water-level depends closely on hydrological fluctuations in southwestern Siberia. Since the end of the nineteenth century, when regular hydrological observations began, a constant fall in the water-level has occurred. This correlates with a decrease in regional humidity. Even so, periodic falls and rises in water-level occur. Thus, by 1914 the level had risen by 1.6 m. It then fell 2.8 m by 1937. It rose again by 2 m until 1950, but by 1971 had again fallen some 1.8 m. The average annual amplitude in water-level is 0.8 m. There are also short term local fluctuations caused by winds; these may reach 0.7–0.8 m (Anon., 1984).

The climate in the Barabinsk steppe is continental, with warm summers and cold winters. The average winter water temperature is 2.0 °C. In summer (July), the water temperature reaches 20.6 °C. The lake is ice-covered by the end of October or beginning of November, but ice disappears by the end of April or the beginning of May. The shallow regions of the lake can be frozen to the bottom. Because of high winds and the shallow depth of the lake, the water-column is always isothermal.

The bottom sediments comprise various silts. Sands cover not more than 12 per cent of the bottom.

The lake is moderately saline, but values differ in different parts of the lake. In 1976, values were from 1.1 to 14.7 $g\,l^{-1}$. The ionic composition is dominated by sodium and chloride ions, and, compared to sea-water, proportions of magnesium and sulphate are higher, and (bi)carbonate much higher, but sodium, potassium and chloride proportions are lower. Salinity is rising, and from 1948–1978 increased from 1.40–4.05 $g\,l^{-1}$ to 8.2–11.8 $g\,l^{-1}$. As ice develops in winter, the salinity increases (Anon., 1984).

Overall, the lake complex is mesotrophic, but the small Lake Chany is eutrophic. Macrophytes include thirteen species of submerged and emergent plants, but only *Phragmites australis* (Cav.) Trin. ex. Steud. and *Potamogeton pectinatus* L. are common. The reed communities are situated at the shore margins and may be to 1 km wide. Due to recent falls in water-level, a significant fraction of the reed swamp is now dry land.

There are 135 species of phytoplanktonic algae, including 69 species of green algae and 46 species of cyanobacteria that together constitute most of the phytoplankton biomass. Phytoplankton is most diverse in the least saline parts of the lake. The phytoplankton biomass (1978) reaches 2.42–62.27 mg l^{-1} in the large Lake Chany and 168 mg l^{-1} in the smaller one (Ermolaev, 1986). As the salinity increases, the proportion of euryhaline species rises, and freshwater forms disappear progressively. Green algae persist to a salinity of 7 g l^{-1}, and cyanobacteria to 10 g l^{-1} (Anon., 1984).

According to Vizer (1986), 57 zooplankton species occur (most in the smaller lake): 27 rotifer species, 21 cladoceran species, and 9 copepod species. The lake is characterized by the development of a freshwater Copepoda-Cladocera complex, species of which develop high biomass and numerical densities. They include *Daphnia longispina* (O.F.M.), *Chydorus sphaericus* (O.F.M.) and *Mesocyclops leuckarti*. The most frequently found rotifers are *Keratella quadrata* and *Brachionus angularis* Gosse. *Arctodiaptomus salinus* occurs in the most saline parts of the lake. The dominant forms in saline parts are the rotifers *Hexarthra mira* (Hudson) and *Filinia terminalis* (Plate), and the cladocerans *Ceriodaphnia reticulata* (Jurine), *Diaphanosoma brachyurum* and *Moina microphthalma* Sars.

Average zooplankton biomass in summer reaches 15 g m^{-3}. Most comprises crustaceans with rotifers constituting <2 percent of the biomass. High zooplankton producton is the basis for a productive commercial fishery (Anon., 1984), but water-level fluctuations have had a negative influence on zooplankton biomass. The sharp fall in levels to 1971 led to a threefold decrease.

The zoobenthos of the Lake Chany complex contains 114 species (Miseyko *et al.*, 1986). Of these, 68 species are insects (45 species of chironomids), 13 are molluscs, 2 are crustaceans, and 3 are annelids. On silts, the larvae of *Chironomus plumosus* predominate, whereas on sand, *C. defectus* Kieff., *Tanytarsus* sp. and *Procladius* sp. predominate. Ceratopogonids and oligochaetes are also numerous. Mollusc numerical and biomass densities are low. In the more saline parts of the lake, the zoobenthos biomass is not high (2.8 g m^{-2} against 23.7 g m^{-2} in less saline parts). The most salt-sensitive forms are oligochaetes. *Chironomus anthracinus* becomes the dominant form in the saline parts (Anon., 1984).

The Lake Chany complex has an important commercial fishery, with annual average catches of 4400 tons. The original fish fauna is represented by the roach (*Rutilus rutilus* Pall.), perch (*Perca fluviatilis* L.), pike (*Esox lucius* L.), ide (*Leuciscus idus* (L.)), and carp (*Carassius carassius* L., *C. auratus*) – all of commercial significance – and by the dace (*Leuciscus leuciscus* L.), gudgeon (*Gobio gobio*), and lake minnow (*Paraphoxinus percnurus* (Pall.)). Roach formerly made up as much as 90 per cent of the catch. In the 1950s and 1960s, several other fish were introduced: carp (*Cyprinus carpio*), tench (*Tinca tinca*), bream (*Abramis brama* (L.)). sander (*Lucioperca lucioperca*), European cisco (*Coregonus albula* L.), peled (*C. peled* (Gmelin)), muksun (*C. muksun* (Pallas)), arctic cisco (*C. autumnalis* (Pallas)) and sheefish (*Stenodus leucichthys*), but of these introductions only bream, sander and carp were successful. The size of the fish catch depends on lake volume. When water-levels are low, catches fall to 300 tons, but at high levels they increase to 9800 tons. Moreover, when water-levels are low, fish reproduction is inhibited: the increased salinity reduces roe survival and there is a reduced area of spawning grounds (most of which are in the smaller lake and the river valleys). Additionally, at low levels, the rate of biomass increase diminishes, and natural mortality increases, especially in winter. For most of the fish the highest salinity at which ova develop and larvae survive is ± 4 g l^{-1}, but for perch this value is 7 g l^{-1} (Anon., 1984).

To retain the commercial fishery it is necessary to maintain the present water-level, or regain former levels. With this in mind, the most saline part of the lake, which had little fishery significance, was isolated from the main lake by a dam. The aim was to maintain lake levels in the reduced area despite a decrease in regional water abundance. There are also plans to withdraw water from the River Ob and divert it into Lake Chany and to establish an outflow from the lake into the River Irtish.

Lake Alakul

Lake Alakul (or *Alakol*) is a terminal lake in the semi-desert zone of Kakakhstan within the Balkhash-Akakul basin at an elevation of 343 m above sea-level. The River Emel discharges into it. Extending northwest to southeast, it is 104 km long, 52 km wide and has an area of 2650 km^2. Maximum depth is 54 m and average depth, 22.1 m. From 1952–1962, water-level rose by 4.25 m. Average annual fluctuations in water-level are 1.2 m. The thermal regime is characteristic of that for deep lakes: in summer, the lake stratifies, but is mixed in autumn following the occurrence of high winds. In summer, surface temperatures reach 24–26 °C, but ice cover is present from January to April (Filonets, 1965; Kurdin, 1965).

Water transparency varies from 0.6–0.8 m in shallow areas to >6 m in central parts. Salinity is highest in the central and eastern parts of the lake (up to 8–10 g l^{-1}). The least saline water is in the northwest (nearly 5 g l^{-1}). Salinity of surface waters is lower (1.1–2.0 g l^{-1}) in winter when the ice cover on the lake suppresses the wind-induced mixing of river inflows with the saline lake water. In other seasons, currents prevent such stratification. In the early 1960s, there was a decrease in salinity following an inflow of fresh water. Ionic composition varies in different parts of the lake (Kurdin & Shilnikovskaya, 1965).

Macrophytes occur throughout the lake, but are most developed in the northwest. The phytoplankton has 156 species, of which diatoms are the most numerous (Logvinovskikh, 1965).

The zooplankton is unevenly distributed. It is most diverse in the least saline parts of the lake in the northwest where shallow depth, indented shorelines and abundant macrophyte vegetation favour zooplankton development. In this region, the dominant forms are *Arctodiaptomus salinus*, *Cyclops* sp., *Ceriodaphnia reticulata*, *Diaphanosoma brachyurum*, *Brachionus angularis*, *B. calyciflorus* Pallas, *Keratella cochlearis* and *Asplanchna herricki* Guerne. Zooplankton biomass here is 1.8–2.9 g m^{-3}. In the southeast, where depths are greater and vegetation less well-developed, zooplankton biomass falls to 0.4–1.0 g m^{-3}. In the central and northern regions, *Arctodiaptomus salinus* and *Eudiaptomus graciloides* Lill. become dominant, the cladocerans decrease in abundance and the rotifers increase in abundance. In the southeast, where rotifers are dominant, the zooplankton biomass decreases to 0.5 g m^{-3}. *Brachionus plicatilis* Muller and *Hexarthra oxyurus* are the main species involved (Loginovskikh & Dyusengaliev, 1972).

The zoobenthos comprises oligochaetes, leeches, insect larvae, and (rarely) molluscs. The principal group is larval chironomids (45 species). Zoobenthos development depends on substrate type and salinity. It is highest on grey silts (3.88 g m^{-2}), and least on silty sands (0.78 g m^{-2}). The highest zoobenthic biomass is found in the northwest (5.73 g m^{-2}), but it is also high in central areas at depths of 30–40 m (5.04 g m^{-2}). The lowest values occur in eastern bays (1.16 g m^{-2}). Overall, the biomass density is 2.61 g m^{-2}, and chironomids dominate everywhere, comprising 96 percent of the total biomass (Loginovskikh, 1965).

Fish are represented by marinka (*Schizothorax argentatus*), carp, (*Cyprinus carpio*) loach (*Nemachilus strauchi*) and perch (*Perca schrenki*). Sander (*Lucioperca lucioperca*) was introduced in the 1960s. Marinka, carp and perch are the commercial species (Nekrashevich, 1965).

Lake Tengiz

Lake Tengiz (*Dengiz*) is an alkaline lake situated in a tectonic basin in the north of Kazakhskiy Melkosopochnik, in the Kurgaldzhi reserve in the

Tselinograd region of Kazakhstan. Its area is 1590 km^2, it is 75 km long, 40 km wide and 8 m deep, and it is surrounded mainly by desert. Some islands occur just off the eastern shoreline. There is a shallow gulf in the northeast. The lake derives most inflow from snow-melt. The bottom is even and partly covered by black silts. In very dry years the lake partly dries out. The dominant ions are sodium and sulphate, and the salinity is 12.7 g l^{-1}, reaching 18.2 g l^{-1} in the gulf. The lake is ice-covered in December, but the ice breaks up in April. Inflowing rivers are the Nura and Kulanutpes. Little is known of the biological features of this lake.

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References

Abrosov, V. N., 1963. Ozero Balkhash. The Lake Balkhash. Leningrad, 'Nauka', 127 pp. (Russian)

Aladin, N. V. & W. T. W. Potts, 1992. Changes in the Aral Sea ecosystems during the period 1960–1990. Hydrobiologia 237: 67–79.

Anon., 1984. Prirodnie Resursy Bolshikh Ozer SSSR i Veroyatnie ikh Izmeneniya. Natural Resources of Large Lakes in the USSR and their Probable Changes. Leningrad, 'Nauka'. 228 pp. (Russian)

Bolshaya Sovetskaya Encyclopedia. 3-e izd. The Large Soviet Encyclopedia. 3rd edition. vols. 1, 2, 25. Moscow, 'Sovetskaya Entsiklopedia'. (Russian)

Domrachev, P. F., 1933. Materialy k fiziko-geograficheskoy kharakteristike ozera Balkhash. Materials on the physico-geographical characteristic of the Lake Balkhash. In Issledovaniya ozer SSSR, v. 4. Leningrad. Studies of the USSR lakes, v.4: 31–56. (Russian)

Domrachev, P. F., 1940. Ozero Balkhash kak obyekt geograficheskogo izucheniya i issledovatelskie raboty, provodivshiesya na nem za poslednee desyatiletie. Lake Balkhash as object for geographical studies and researches carried out on it in the last decade (1928...1938). In Izvestiya Vsesoyuznogo Geograficheskogo Obschestva, v. 72, No. 6. Proceedings of the All-Union Geographical Society: 651 pp. (Russian)

Ermolaev, V. I., 1986. Planktonnie fitotsenozy ozera Chany. Plankton phytocenoses of Lake Chany. In Ecologiya ozera Chany. Moscow 'Nauka'. Ecology of Lake Chany: 76–87. (Russian).

Filonets, P. P., 1965. Morfometria Alakolskikh ozer. Morphometry of the lakes of the Alakol system. In Alakolskaya vpadina i ee ozera. Alma-Ata, 'Nauka'. The Alakol hollow and its lakes: 79–87. (Russian)

Foliyan, L. A., 1973. Zooplankton ozera Issyk-Kul (kachestvenny sostav). Zooplankton of Lake Issyk-Kul (qualititative composition). In Ikhtiologischeskie i gidrobiologicheskie issledovahiya v Kirgizii. Frunze, 'Ilim'. (Ichthyological and hydrobiologycal studies in Kirgizia: 3–11. (Russian)

Karpevich, A. F., 1975. Teoria i praktika akklimitaztsii vodnykh organizmov. Theory and practice of acclimatization of aquatic organisms. Moscow, 'Pischevaya Promyshlennost' 432 pp. (Russian).

Kipshakbaev, N. K. & Zh. E. Baygisiev *et al.*, 1985. Sistemniy analiz Ili-Balkhashskoy problemy i kontseptsiya ravnovesnogo priridopolzovaniya. System analysis of the Ili-Balkhash problem and conception of balanced nature managment. In Problemy komplexnogo ispolzovaniya vodnykh resursov Ili-Balkhashskogo basseyna. Izd. Kazakhskogo Gos. Universiteta, Alma-Ata. Problems of complex nature resources management in the Ili-Balkhash basin: 80 pp. (Russian)

Kurdin, R. D., 1965. Termicheskiy rezhim Alakolskikh ozer. Thermic regime of the Alakol system lakes. In Alakolskaya vpadina i ee ozera. Alma-Ata, 'Nauka'. The Alakol hollow and its lakes: 182–195. (Russian)

Kurdin, R. D. & L. S. Shilnikovskaya, 1965. Gidrokhimicheskiy rezhim Alakolskikh ozer. Hydrochemical regime of the Alakol system lakes. In Alakolskaya vpadina i ee ozera. Alma-Ata, 'Nauka'. The Alakol hollow and its lakes: 209–222. (Russian)

Loginovskikh, E. V., 1965. Kormovaya baza Alakolskikh ozer i ee ispolzovanie rybami. Food basis of the Alakol lakes and its use by fishes. In Alakolskaya vpadina i ee ozera. Alma-Ata, 'Nauka'. The Alakol hollow and its lakes: 223–235. (Russian)

Loginovskikh, E. V. & T. Dyusengaliev, 1972. Kolichestvennaya kharakteristika zooplanktona Akakolskikh ozer. Quantitative characteristics of the zooplankton of the Alakol lakes. In Rybnie resursy vodoemov Kazakhstana i ikh ispolzovanie, vyp. 7. Alma-Ata, 'Kaynar'. Fish resources of Kazakhstan waterbodies, v. 7: 89–94. (Russian)

Miseyko, G. N., L. L. Sipko & V. V. Kryzhanovskiy, 1986. Zoobenthos ozera Chany. Zoobenthos of Lake Chany. In Ecologiya ozera Chany. Novoskibirsk, 'Nauka'. Ecology of Lake Chany: 128–146. (Russian)

Nekrashevich, N. G., 1965. Materialy po ikhtiofaune Alakolskikh ozer. Materials on the ichthyofauna of the Alakol lakes. In Alakolskaya vpadina i ee ozera. Alma-Ata, 'Nauka'. The Alakol hollow and its lakes: 236–268. (Russian)

Panov, A. P., 1933. Khimicheskaya otsenka vody ozera

Balkhash. Chemical appreciation on the Lake Balkhash water. In Issledovaniya ozer SSSR, v. 4. Leningrad. Studies of the USSR lakes, v. 4: 105–112. (Russian)

Rylov, V. M., 1933. K svedeniyam o planktone ozera Balkhash. Information on the lake Balkhash zooplankton. In Issledovaniya ozer SSSR, v. 4. Leningrad. Studies of the USSR lakes, v. 4: 57–70. (Russian)

Saduakosova, R. E., 1972. Zooplankton ozera Balkhash. Zooplankton of Lake Balkhash. In Rybnie resursy vodoemov Kazakhstana i ikh ispolzovanie, vyp. 7 Alma-Ata, 'Kaynar'. Fish resources of Kazakhstan water-bodies, v. 7: 97–100 (Russian)

Tarasov, M. N., 1965. Gidrokhimiya ozera Balkhash. Hydrochemistry of the Lake Balkhash. Leningrad, Gidrometeoizdat', 371 pp. (Russian).

Tursunov, A. A. *et al.*, 1986. O sostoyanii problem Ili-Balkhashskogo basseyna. On the Ili-Balkhash basin state problem. In: Voprosy gidrologii oroshaemykh zemel Kazakhstana. Alma-Ata, 'Nauka'. Problems of hydrology of irrigated lands in Kazakhstan, 161 pp. (Russian).

Vizer, L. S., 1986. Zooplankton ozera Chany. Zooplankton of Lake Chany. In: Ecologiya ozera Chany. Novosibirsk, 'Nauka'. Ecology of Lake Chany: 105–114. (Russian).

Voskoboynikov V. A., A. N. Gundrizer, B. G. Ioganzen, S. F. Kononov, V. M. Kraynov, G. M. Krivoschekov, N. A. Nesterenko, Yu. F. Malyshev, M. I. Feoktistov, V. A. Schenev, 1986. Obschiy ocherk ikhtiofauny ozera Chany. General feature of the Lake Chany ichthyofauna. In: Ecologiya ozera Chany. Novosibirsk, 'Nauka'. Ecology of Lake Chany: 158–196. (Russian).

Williams, W. D. & N. V. Aladin, 1991. The Aral Sea: Recent limnological changes and their conservation significance. Aquatic Conservation 1: 3–17.

Zenkevich, L. A., 1963. Biologiya morey SSSR. Biology of the seas of the USSR. M., Izd. AN SSSR 739 pp. (Russian).

Zhandaev M. Zh., 1972. Geomorfologiya Zailiyskogo Alatau i problemy formirovaniya rechnykh dolin. Geomorphology of Zailiyskiy Alatau and problems of river valleys forming. Alma-Ata, 'Nauka', 159 pp. (Russian).