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Preface: Value and dynamics of salt lakes in a changing world

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The statement that the world's ecosystems are rapidly deteriorating due to human intervention and global warming is nowadays commonplace. Some of the ecosystems most heavily impacted are inland salt lakes. The salt lakes are among the most valuable and fascinating ecosystems on Earth, and their study has both basic scientific interest as well as applied aspects.

Many of the world's saline and hypersaline lakes are rapidly shrinking. Global warming and climate change are in part responsible for the drying out of salt lakes, but in most cases, diversion of freshwater from the lakes' drainage areas for irrigation and other forms of human use is the major cause of their decline (Wurtsbaugh et al., 2017). Great Salt Lake, Utah (USA) is a dramatic example. The north arm is now at, or near, salinity saturation. Today the lake is 3.6 m below its 1847 level and contains just half its original volume. The rapid drying-out of the lake was mainly due to consumptive water use (Deroulin, 2017; Wurtsbaugh et al., 2017). Until 2–3 decades ago, Lake Urmia (Iran), located in Iran's northwestern corner at an elevation of 1 275 m above sea level, covered ~6 000 km^2, being even larger than Great Salt Lake. It had a rich ecosystem that included *Artemia urmiana* (known only from Lake Urmia and from two Crimean hypersaline lakes), used as feed by flamingos and other waterfowl. After the rivers that supplied most of the water to the lake had been dammed for irrigation and hydropower, less than 10% of the original lake surface is left, exposing a salt desert; the beautiful ecosystem was destroyed. Attempts are underway to restore the brine shrimp populations and the accompanying wildlife in small embayments (Stone, 2015). It was estimated that annually 3.7×10^9 m^3 water is needed to preserve Lake Urmia. With the current climate change, even the reduction of water diversion and irrigation will not stabilize the ecosystem (Shadkam et al., 2016).

In 1960, the Aral Sea, located between Kazakhstan and Uzbekistan, was the fourth largest lake in the world by water surface area with a total area of 68 500 km^2 and a volume of 1 089 km^3. The maximum depth was 69 m. The lake was only slightly saline (average salinity ~10 g/L). The lake was inhabited by 12 species of fish and ~160 species of free-living invertebrates, not including protozoa and small-size metazoa. By 2007 the Aral covered ~13 958 km^2 (21% of 1960) with a volume of 102 km^3 (9% of 1960). The Large Aral (the southern part) had an area of 10 700 km^2 (17% of 1960) and a volume of 75 km^3 (8% of 1960), salinity being >100 g/L. The respective values for the Small Aral were 3 258 km^2 (53% of 1960) and 27 km^3 (33% of 1960), with an average salinity of about 10 g/L. The lake has split into six separate water bodies. All this was mainly caused by diversion of freshwater from the catchment area (Aladin et al., 1995; Micklin, 2007; Micklin and

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Aladin, 2008).

Another salt lake that is rapidly declining is the Dead Sea. Comparison of the history of the Aral Sea and the Dead Sea, their deterioration due to human interference and climatic changes, and attempts to restore the ecosystems, shows many common features (Oren et al., 2010).

Not only are these large saline lakes affected by water diversions and climate change. There are many others located in vulnerable regions and climatic zones. For example, the saline lakes on the Mongolian Plateau experienced significant shrinkage during the past several decades. The deterioration of lakes is expected to continue in the coming decades, not only because of changing the climate but also because of increasing exploitation of underground mineral and groundwater resources on the plateau (Tao et al., 2015). Projections show that the Mediterranean climate zone will be markedly affected, with significant implications for lake water levels and salinity. This may be exacerbated by increased demands for irrigation water. Based on long-term data from seven lakes and reservoirs covering a geographical gradient of related latitudes and on a literature review, it was projected that the decline in water level and the increase of salinity related to climate change and water abstraction will affect the ecosystem structure, function, biodiversity, and ecological state of lakes and reservoirs (Jeppesen et al., 2015).

Salt lakes are fascinating environments for the exploration of their biota, microorganisms as well as macroorganisms. Such investigations are important as the diversity of the microbial communities and their activities are excellent indicators of the state of the lakes with respect to salinity, nutrients, and other environmentally important parameters. Understanding of the biological processes is also essential for the prediction of environmental changes that may take place when large-scale projects will be implemented to mitigate the drying out of the world's large hypersaline lakes. For Great Salt Lake and the Dead Sea, we have a relatively good understanding of the microbial communities and the processes they perform, but much remains to be learned about the microbes inhabiting these lakes and the impact of possible future changes, climatic as well as man-made, on the physical and chemical properties of their waters. Other major salt lakes such as Lake Urmia and the Aral Sea remain virtually unexplored as far as the microbial communities are concerned. Recently, Paul and Mormile (2017) issued a call for the protection of saline and hypersaline environments from a microbiological perspective. Saline lakes worldwide are threatened by increased salinization due to water diversions, global climate change, industrial processes, pollution, and other factors. An in-depth knowledge of the microbial populations and the biogeochemical processes they perform is essential for the proper understanding of the current functioning of salt lake ecosystems and for the prediction of the consequences of future changes in these unique environments.

The understanding of the animal and plant life of saline lakes is essential for their exploitation and for the conservation of their ecosystems with the support of ecosystem services provided by these lakes for human society. The Aral Sea was an important source of the commercial fishery, and the brine shrimp *Artemia* is an important economical resource in Great Salt Lake, Lake Urmia and hundreds of smaller lakes around the world. Some saline lakes are designated Ramsar sites and serve as permanent or temporary refuges for rare and threatened birds. Iconic bird species associated with saline lakes are flamingos. The Torey lakes located in Central Asia on the border of Russia and Mongolia are an important stop and feeding point for millions of birds travelling the East Asian—Australian Asian flyway. Many saline lakes attract tourists, mostly because of their scenic views and the therapeutic properties of their saline waters and muds. Many saline lakes are exploited for the extraction of minerals (Zheng, 2014). Thus, most of the world's lithium resources are located in hypersaline lakes or remnants of saline lakes located in enclosed basins.

Variations in water level and the resulting changes in salinity control the biodiversity and the community structure of plankton and macroorganisms, affecting the possibilities of the exploitation of saline lakes. For example, the water level decline may lead to an increase in salinity, a decrease of zooplankton biodiversity, and elimination of fish. This can abolish fishery activity but opens the opportunity for *Artemia* production or salt extraction. Lake Qarun (Egypt) is an example of this (Shadrin et al., 2016). The decline of zooplankton and plant life may threaten birds that rely on these resources during seasonal migration. On the other hand, increased water level and decreased salinity in some lakes may diminish their attractiveness as natural spas. Lake Kyzyl-Yar, Crimea, Russia, is an example (Shadrin et al., 2018). Thus, there are complex interactions of different processes (physical, ecological, biological, social, and economic) that require adequate management instruments and policies.

All these aspects of inland saline lakes, and many others, are discussed during the triennial conferences organized by the International Society for Salt Lake Research. These conferences bring together experts on many aspects of salt lake research: limnology, geology, geochemistry, botany, zoology, microbiology, engineering, history, and more. This collection of papers presented in this special issue of the *Journal of Oceanology of Limnology* is based on presentations held during the 13th International Conference on Salt Lake Research, organized by the International Society for Salt Lake Research in Ulan-Ude, Republic of Buryatia, Russia, on August 21–25, 2017. This most recent of the triennial conferences organized by the society was attended by 122 delegates from 15 countries. A number of presentations at the symposium dealt with freshwater systems that can be used as model systems for comparison, and therefore the present collection of papers includes some articles that deal with freshwater environments.

The conference venue was not far from one of the few meromictic lakes in Siberia—Lake Doroninskoe, and some of the participants visited this still under-investigated lake during the post-conference field trip. Another Siberian meromictic lake, Lake Shira, attracted much research in past 20 years. Therefore, it is not surprising that Lake Shira featured in several presentations at the symposium. Prokopkin and Zadereev used a numerical model to estimate the response of Lake Shira, a meromictic lake ecosystem, to variations in weather parameters. Compared to other external (nutrients inflow) and internal (spring biomasses of food-web components) factors, weather parameters during the summer season strongly control the mixing depth, water temperature and mixolimnetic food-web (phyto- and zoo-plankton) and monimolimnetic (purple sulfur bacteria, sulfur reducing bacteria and hydrogen sulfide) food-web components. Calculations based on different weather scenarios demonstrated how changes in the water temperature and mixing depth affect these mixolimnetic and monimolimnetic food-web components and the depth of the oxic-anoxic interface in a meromictic lake. Intra- and inter-annual climate and weather effects will be more important for the control of meromixis stability (Prokopkin and Zadereev, 2018).

Understanding the geochemistry of major as well as minor elements is an important part of salt lake science. Geochemical topics are therefore featured in a number of papers. Xu et al. (2018) studied the seasonal variations of phosphorus species in the sediments of the Tuohe River, China, one of the largest tributaries of the Changjiang (Yangtze) River, to provide information on the transport and transformation of phosphorus. Biologically available phosphorus represents only a minor portion of the total phosphorus. The vertical distribution of soluble reactive phosphorus suggests that bio-available phosphorus may be converted to non-bioavailable phosphorus in the deeper layer of the sediment (Xu et al., 2018). The seasonal speciation of antimony at the sediment-water interface of Poyang Lake, the largest freshwater lake in China, as based on a laboratory simulation study, is reported by Yu et al. The seasonal temperature plays an important role in the migration and transformation behavior of antimony, especially of the organic fraction, in porewaters and in the overlying water. Antimony migrates from porewaters to the overlying water when the temperature decreases, and the equilibrium between Sb(III) and Sb(V) in porewaters shifts toward Sb(V) when the temperature rises. Decreasing temperature causes enrichment of antimony in the sediment (Yu et al., 2018). Tereshchenko and coworkers studied the distribution of plutonium ($^{239+240}$Pu and ^{238}Pu) in salt lakes of different nature and geographical location in the Crimean peninsula. The ratio of the activities of ^{238}Pu/$^{239+240}$Pu in the upper sediment layers was calculated to estimate the percentage of Chernobyl and global origin plutonium in the lakes. The percentage of the plutonium radionuclides from the Chernobyl accident was up to 16% (Tereshchenko et al., 2018).

Microbiology-related subjects are the topic of four more papers. Krasnova et al. analyzed the nature of the characteristic pattern of multiple colored layers in coastal stratified lakes in the process of separation from the White Sea due to ongoing postglacial uplift. An upper greenish colored layer with green algae was found in the aerobic strata of all lakes near the light compensation depth. A brightly green, red or pink layer in the chemocline is dominated by mixotrophic flagellates with high photosynthetic activity, despite the very low light intensities and the presence of sulfide. In the reduced zone of the chemocline, a dense green or brown suspension of anoxygenic green phototrophic sulfur bacteria is located (Krasnova et al., 2018). Another interesting coastal hypersaline system was studied by Newton et al.: the Coorong estuary located at the terminus of Australia's largest river system, the Murray-Darling. Metagenomic approaches were used to determine the planktonic bacterial community composition and potential metabolic function at two extremes in the Coorong: the river mouth which exhibits marine-like salinity and the hypersaline upper-reaches of the estuary. Significant shifts in taxa composition and metabolic function were observed between the two sites. An over-representation of taxa and metabolic types indicative of environmental change is reflective of anthropogenically affected riverine input. In the hypersaline upper reaches of the estuary, there is a dominance of halophilic and halotolerant types. The Coorong exhibits a unique planktonic bacterial community that is influenced by riverine input at the river mouth and salinity in the upper-reaches (Newton et al., 2018).

Komova and coworkers studied the chemical and biological features of the saline lake Krasnovishnevoye, Baraba steppe, Russia, with a total dissolved solids concentration near 300 g/L, and compared the findings with those for Lake Malinovoe, a saline neutral lake of the Kulunda steppe with close to 400 g/L salts. The phytoplankton composition and the culturable diversity of anoxygenic phototrophic bacteria were similar, but the peculiarities of water and mineral composition of Lake Krasnovishnevoye reduces the biodiversity to prokaryotes and unicellular algae there (Komova et al., 2018). Finally, Matyugina et al. (2018) report on the diel changes in the microbial community structure of the above-mentioned meromictic Lake Doroninskoe, Transbaikalia, Russia, as studied by high-throughput sequencing and bioinformatic tools. This lake has an unusual type of alkaline water and a low light intensity at the chemocline. Statistically significant differences were found between the microbial communities during the day and the night (Matyugina et al., 2018).

The last group of papers in this special salt lakes issue of this journal deals with macroscopic organisms. Prazukin and coworkers report on the structure, dynamics and photosynthetic activity of mats of the filamentous green alga *Cladophora* in a hypersaline lake in the Crimea. The alga dominates in the benthic and floating mats that occupy large areas with up to 4–5 kg wet biomass/m^2. Different animals, including copepods, ostracods, and chironomid larvae reach high densities in these mats (Prazukin et al., 2018). Based on analyses of data collected from different salt lake ecosystems, Shadrin (2018) concluded that such ecosystems may exist in multiple stable states and may demonstrate regime shifts, which are large, abrupt, persistent changes in the structure and function of the system. Salt lakes are excellent model systems to test the emerging concept of multiplicity of ecosystem alternative stable states. He further discusses how to base the environmental management of salt lake on the developing paradigm, and how this can be applied to salinology as a scientific basis of an integrated management of a saline lake and its watershed. Timms (2018) reports on the phenology of invertebrates in Australian saline lakes, with special reference to those of the Paroo in the semiarid inland. Southern Australian lakes fill in early winter and remain at salinities characteristic for each lake during winter-spring before drying in summer. Their fauna is dominated by crustaceans with almost no insects. Lakes in the southern inland such as Lake Eyre fill in summer, change little in salinity until near drying, and are dominated by crustaceans with some insects present as well. By contrast, temporary salinas in the central inland fill episodically mainly in summer and then their salinity increases steadily as they dry without further rain. Their fauna is also dominated by crustaceans, but with a significant insect component, and their composition varies though the hydrological cycle.

The cue hierarchy in the foraging behaviour of the brackish cladoceran *Daphniopsis australis*, an important and endemic component of South Australian saline inland water ecosystems, was studied (McCloud et al., 2018). The swimming behaviour of males, parthenogenetic females and ephipial females was investigated under various conditions and combinations of food and conspecific cues. In the absence of cues, males displayed the most extensive swimming behavior, exploring all areas of the container, and swimming in a series of relatively straight trajectories. In contrast, females typically exhibited a hop-and-sink motion characterized by the alternation between short bursts of swimming and sinking phases. In the presence of cues, males and females all showed abilities to detect infochemicals from food and conspecifics but exhibited specific behavioral strategies. Aladin and coworkers present a survey of the past and future of the biological resources (organisms that can be used by man directly or indirectly for consumption) of the Caspian and the Aral Seas. The most important biological resource of the Caspian Sea and the Aral Sea is their ichthyofauna, represented by both aboriginal and introduced species. Among the invertebrates, the main biological resource in the saline Aral Sea and the hypersaline Bay Kara-Bogaz-Gol (Caspian Sea) is the brine shrimp *Artemia*. The state of the Caspian Sea is almost stable. Since the second half of the 20th century, the Aral Sea is experiencing anthropogenic regression, which led to almost complete loss of its biological resources due to salinization. But, thanks to the measures taken, it has now become possible to preserve its northern part (Small Aral) and rehabilitate it, lowering its salinity. The result was the restoration of its fish resources. In the southern part of Aral (Large Aral), which turned into a group of hypersaline reservoirs, the only resource species currently is the brine shrimp (Aladin et al., 2018). The final paper discusses the potential, as yet very little exploited, of saline and hypersaline lakes for aquaculture development. A way to overcome the increasing demand for fresh water in aquaculture systems is to develop aquaculture in saline lakes. The paper presents a list of fish and shrimp species that can be cultivated in saline lakes, and some of these can tolerate very high salt concentrations. Thus, there is a high potential to use eukaryotic organisms of different taxa in saline and hypersaline aquaculture for food and food supplements (Anufriieva, 2018).

As the guest editors of this special issue, we want to thank the publisher and the editors of the *Journal of Oceanology and Limnology* for offering us to dedicate an issue of the journal to the proceedings of the Ulan-Ude saline lakes conference. We thank the reviewers for their comments that improved the quality of the papers. We hope you enjoy the papers in this special issue, and we are looking forward to seeing all those interested in salt lakes at the 14th International Conference on Salt Lake Research, to be held in Murcia, Spain, in 2020.

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