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Impacts of water level changes in the fauna, flora and physical properties over the Balkhash Lake watershed

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Abstract
The water level variations of the Lake Balkhash, the Kapshagay Reservoir and the Ili River and the linkage with salinity and biological conditions are investigated in this work using different techniques: satellite radar altimetry, in situ gauges, historical archives of fish population counting and field works. We show that it is possible now to monitor, over decades, in near real time, with high precision, the water level changes in the Lake Balkhash from satellite altimetry, over the reservoir and also along the Ili River. The vulnerability of the lake fauna and flora populations is enhanced by the morphometry of the lake: shallow and separation of the eastern basin from the western basin through the narrow Uzun-Aral strait. Water policy of the Ili River also plays a fundamental role in the evolution of the Balkhash Lake. The Ili River that provides 80% of the surface water of the lake is a transboundary river. Development of intense irrigated agriculture in the upstream part of this river, located in the Chinese territory, could lead in the future to high hydrological stress in the downstream regions with potentially high damage in the delta and for fishery production. We show here the recent evolution of the Lake Balkhash basin from satellite data. Some interannual oscillation of 6–8 years over the last decade has been highlighted, with a water level of the lake still at a high value, but prediction on increasing irrigation is also highlighting the vulnerability of this lake. Linkage between water level change along the river and the downstream waters is also investigated. It shows that the role of the reservoir is not fundamental in the understanding of the Lake Balkhash water level changes which is in contrast highly correlated to upstream river level changes.

KEYWORDS
Balkhash Lake, hydrology, ichthyofauna, lake management, phytoplankton, satellite altimetry, water level, water salinity, zoobenthos, zooplankton

1 | INTRODUCTION

1.1 | Lake Balkhash settings

Lake Balkhash is located in eastern Kazakhstan in a depression at an altitude of ~340 m a. s. l. in the Balkhash-Alakol desert. The climate of this region is arid and continental. Lake Balkhash stretches from east to west over 600 km. Its width is ~74 km in the western part and 9–19 km in the eastern part. The western and northern shores are high and rocky. The southern ones are low-lying, sandy and fringed by dense reeds and swamp. The water surface area of the lake is variable and depends on its level and ranges 17,000–22,000 km^2. In the 1960s, the maximum depth was 27 m. The average depth of the lake is 5.8 m, and the total water volume is about 106 km^3 (Alekin, 1984; Domrachev, 1933; Semenov & Kurdin, 1970).

Saryesik peninsula divides the Lake Balkhash into the two distinct parts. The western part is larger by area (more than 10,000 km^2) and shallow (up to 11 m). The eastern part has a lower area (more than 7,000 km^2) but is deeper (up to 26 m). These two parts of the lake are connected by narrow (width about 3.5 km) and shallow (about 3 m) strait, the Uzun-Aral. Consequently, the water exchange between them is hampered and they are relatively independent aquatic systems. This is a fundamental feature of the Lake Balkhash which also makes it half-saline lake (East) and half freshwater lake (West).

1.2 | Lake Balkhash water balance

The Lake Balkhash is a closed terminal lake. Incoming part of its water balance consists of surface run-off (riverine flow and spring run-off from the coastal zone), precipitations and groundwater run-off. The main volume of water flowing into the lake (about 80%) is given by the rivers. The losses consist of evaporation from the lake surface (in arid climate, it consumes almost all the incoming water) and water infiltration into the lake bed (Yunusov, 1950; Zhirkevich, 1972).

The catchment area of the Lake Balkhash is about 413,000 km^2. Its main part (about 80%) is located in Kazakhstan, and the rest is lying in China and Kyrgyzstan. Five rivers, all formed and fed by glaciers located in the mountain south to the lake's basin, flow into the Lake Balkhash. The only river flowing into the western part of the lake, the Ili, supplies up to 80% of the total riverine run-off entering the lake. Its run-off into the lake is up to 12.3 km^3/year, and almost 90% of it is formed on the territory of China. All other rivers—Karatal, Aksu, Lepsy and Ayaguz—are flowing into the eastern part of Balkhash. Their common run-off is small and comparable with the incoming water on the lake's surface from atmospheric precipitation. The second largest tributary is Karatal River. Currently, water of Ayaguz River reaches the lake only during flood time (Alekin, 1984).

The Lake Balkhash's level, as closed terminal water body in arid climate, is unstable and is highly dependent on climate change in the region. For example, in the history, the Lake Balkhash oscillated between high (transgression phase) and low (regression phase) levels (that took place in 400, 1,000–1,250 and 1,500–1,600). The first two correspond to the Medieval Warm Period with its arid conditions while between 1,250 and 1,500, and after 1,600, there was a rapid rise in the lake level linked to the Little Ice Age (Endo et al., 2012). It is possible that lake level during the Medieval Warm Period was at 8.7 m below the present maximum level. In contrast, after 1,600, during the Little Ice Age water level was higher.

From 1911 to 1946, the Lake Balkhash's level fell by 3 m from 344 to 341 m a. s. l. This followed by 15 years of increase up to 343 m a.s.l. (Petr, 1992). Until 1970, the lake level kept stable but the construction of the Kapshagay Reservoir on the low reach of the Ili River changed the situation.

In the modern time, the level of Lake Balkhash is experiencing considerable cyclical fluctuations and largely depends on the volume of riverine run-off incoming the lake, especially of Ili River. Until 1970, the changes in the water balance of the Balkhash Lake were driven by climatic factors and losses in the delta (Dostay, Alimkulov, Tursunova, & Myrzakhmetov, 2012; Matsuyama & Kezer, 2009). After the construction of the Kapshagay Reservoir (capacity of 28 km^3), and the development of irrigation along the course of the river, from the upstream part in China to downstream part in Kazakhstan, a drastic change in the riverine run-off was observed: a drop of about 2 m of the Lake Balkhash between 1970 and 1987 (Matsuyama & Kezer, 2009). Then, from 1987 to 2005, the Balkhash water level rose again up to 343 m. This was the result of increasing moisture in the region, as well as additional water incoming from the Ili River due to melting of mountain glaciers. Since 2006, two cycles of ~6 years with amplitude of level variations of ~50 cm have been observed, and in January 2018, the water level was close to its maximum over the last 12 years: ~343 m (see Hydroweb site: http://hydroweb.theia-land.fr/hydroweb/view/89f68be2-c60b-5334-a571-b8143ad02e1c?xml:lang=fr&basin=Balkhash).

1.3 | Lake Balkhash water and bottom sediments

Water level changes in the Lake Balkhash have a strong influence on its hydrological characteristics. Reducing or increasing of the water level, and accordingly the amount of water in the lake, is accompanied by an increase or decrease in the salinity.

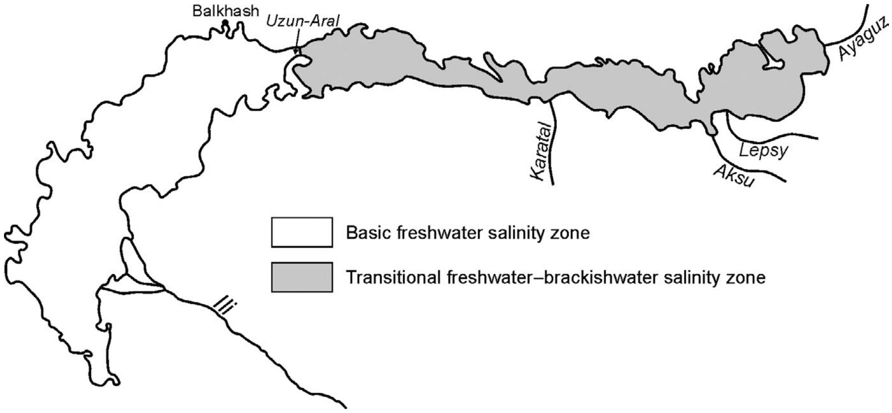
Average salinity of the Lake Balkhash waters is 2.2–2.94 g/L. At that, its western and eastern parts differ in salt regimes and salinity. Western Balkhash is strongly freshened and its average salinity is very low—1.1–1.6 g/L, while in the eastern part of the lake it raises up to 3.3–4.7 g/L, reaching 6–7 g/L in its eastern shallow waters (Sechnoy, 1974; Tarasov, 1961). This is linked to the localization of the rivers supplying fresh water into the lake: the principal one, the Ili, representing 80% of the total inflow to the lake, enters the western part when water exchange through shallow Strait Uzun-Aral is hardly done.

The western part of the Lake Balkhash is occupied by freshwater salinity zone. Eastern Balkhash belongs to transitional brackish-freshwater salinity zone (Figure 1). They are separated by δ-horohalinicum barrier salinity in the area of Uzun-Aral Strait (Aladin & Plotnikov, 2013).

Mineralized waters of the Lake Balkhash are strongly metamorphosed, and its ionic composition is significantly different from the ocean waters and the waters of the Caspian Sea and the Aral Sea (Alekin, 1984). The lake water's proportion of chloride ions (9–21 equiv. per cent) is by 2–3 times lower than in the oceanic water. Proportions of potassium, calcium and magnesium, sulphate, and carbonate/bicarbonate ions are much higher. In the Eastern Balkhash, the proportion of potassium ions (2.9 equiv. per cent) is significantly high in comparison with other waters (e.g., in the ocean and the Aral Sea, it is only of 0.6 equiv. per cent). The lower proportion of calcium ions, especially in comparison with the Aral and Caspian seas, also is notable (Alekin, 1984; Panov, 1933).

Waters of Balkhash are alkaline; pH is 8.0–9.4 increasing from west to east (Krupa, Stuge, Lopareva, & Shaukharbaeva, 2008).

FIGURE 1 Lake Balkhash



Water transparency in the eastern part of Lake Balkhash is higher, reaching 5.5 m. In the western part, the water is more turbid and its transparency is lower, only ~1 m. Water temperature at the surface in June reaches 28°C, and in December, it falls to 0°C. During summer, the temperature difference between the surface and hypolimnion is <3.3°C. Aerobic conditions dominate in the Lake Balkhash in general (Abrosov, 1973), while in shallow waters, areas occupied by vegetation, a small deficit of oxygen can be observed.

Bottom sediments are mainly slimy, but there are sandy grounds. Also, there are layers of peat and "balkhashit", a specific sort of sapropel, can be found somewhere (Abrosov, 1973; Ruschev, 1976).

2 | LAKE BALKHASH BIOTA AND ITS EVOLUTION

2.1 | Aquatic flora

In Lake Balkhash, >350 species and varieties of algae are known. The most rich in the species are diatoms (Bacillariophyceae)—>200, green algae (Chlorophyta)—~65, blue-green algae (Cyanobacteria)—~50 species and varieties. Other taxa have in the lake lower species diversity: dinoflagellates (Dinophyta)—8, golden algae (Chrysophyceae)—4, yellow-green algae (Xanthophyceae)—1, euglenids (Euglenophyceae)—6, Zygnematophyceae—18, Charophyceae—some species (Abrosov, 1973).

Most forms of algae in Balkhash are fresh water (oligohalobionts) or euryhaline (77%), but also there are several halophiles (9%), halobionts (4%) and mezohalobionts (10%). Benthic algae are mainly diatoms and charophyceans (Abrosov, 1973; Alekin, 1984; Karpevich, 1975).

The basis of planktonic algal flora of Lake Balkhash was a small number of species (Abrosov, 1973). In the past, they were: cyanobacteria *Microcystis flosaquae* (Wittrock) Kirchner, *Snowella lacustris* (Chodat) Komárek & Hindák, *Planktolyngbya contorta* (Lemmermann) Anagnostidis & Komárek, *P. limnetica* (Lemmermann) Komárková-Legnerová & Cronberg. *Nodularia spumigena* Mertens ex Bornet & Flahault; dinoflagellates *Ceratium hirundinella* (Müller) Dujardin, *Peridiniopsis borgei* Lemermann; green algae *Pediastrum duplex* Meyen, *Pseudopediastrum boryanum* (Turpin) Hegewald; diatoms *Aulacoseira granulata* (Ehrenberg) Simonsen, *Campylodiscus clypeus* (Ehrenberg) Ehrenberg ex Kützing, *Coscinodiscus lacustris* Grunow, *Cymatopleura elliptica* (Brébisson) Smith, *Entomoneis paludosa* (Smith) Reimer. In the eastern part of the lake, diatoms *Chaetoceros* spp., dinophytes *Chrysosporum bergii* (Ostenfeld) Zapomelová, Skácelová, Pumann, Kopp & Janecek, *Glenodinium berghii* Lemmermann were common.

In the structure of phytoplankton, changes have occurred. In 1973–1985, the common species were cyanobacteria *Merismopedia minima* Beck, *M. tenuissima* Lemmermann, *Snowella lacustris*, *Microcystis pulverea* (Wood) Forti, *Coelosphaerium dubium* Grunow, diatoms *Cyclotella comta* (Ehrenberg) Kützing, *C. meneghiniana* Kützing, green *Oocystis submarina* Lagerheim. In Eastern Balkhash, species of genera *Cyclotella*, *Snowella* and *Chaetoceros* dominated.

In the 2000s, the most common were dinophyte *Peridinium* sp., diatoms *Cyclotella meneghiniana*, *Navicula* sp., euglenophyte *Trachelomonas* sp., green alga *Franceia* sp., cyanobacteria *Snowella lacustris*, *Gomphosphaeria aponina* Kützing and *Gloeocapsa* sp. (Barinova, Krupa, & Kadyrova, 2017).

In the Lake Balkhash, the phytoplankton species composition changes in salinity gradient from west to east. In the western part of the lake, freshwater and euryhaline forms are dominating. To the east, freshwater forms disappear and are replaced by halophiles and mezohalobionts. With increasing salinity, some halophiles spread from east to west (Abrosov, 1973).

The basis of phytoplankton of Western Balkhash is freshwater species. In the past, in the west dominated cyanobacteria *Aphanizomenon flosaquae* Ralfs ex Bornet & Flahault, *Microcystis flosaquae*, *Planktolyngbya contorta* (Lemmermann) Anagnostidis & Komárek and *P. limnetica* (Lemmermann) Komárková-Legnerová & Cronberg, diatoms *Aulacoseira granulata*, *Ceratium hirundinella* Dujardin, *Coscinodiscus lacustris*. To the east, *A. granulata* still predominated, with a significant development of the dinophyte *C. hirundinella*, diatoms *Coscinodiscus lacustris*, cyanobacteria *M. flosaquae*, *Snowella lacustris*, *Nodularia spumigena*. Abundance of *Planktolyngbya* spp. reduced significantly. In the southern part, *A. granulata* and *Ceratium hirundinella* predominated. In the northeast, the abundance of *A. granulata* decreases, and *C. hirundinella* increased. In Eastern Balkhash, composition of phytoplankton changed. In the west, freshwater diatoms *Aulacoseira granulata* almost disappear. A fairly large number of halophilic species are observed: dinophyte *Peridinium latum*, cyanobacteria *Snowella lacustris*, *Nodularia spumigena*, green alga *Microcystis flosaquae* and diatom *Coscinodiscus lacustris*. Diatom *Ceratium hirundinella* were rare. In the plankton, there are brackish-water species: diatoms *Entomoneis paludosa*, *Surirella striatula* Turpin, *Campylodiscus clypeus*. In the middle part of East Balkhash, brackish-water cyanobacteria *Nodularia spumigena*, dinophyte *Peridiniopsis borgei* and diatom *Campylodiscus clypeus* become abundant. Cyanobacteria *Limnococcus limneticus* (Lemmermann) Komárková, Jezberová, O. Komárek & Zapomelová, *Snowella lacustris* and diatoms *Chaetoceros* spp. were numerous. *Ceratium hirundinella* and other dinophytes almost disappeared, except of *Entzia acuta*. The numbers of brackish-water benthic diatoms *Anomoeoneis costata* (Kützing) Hustedt, *Gyrosigma strigile* (Smith) Cleve, *Pleurosigma elongatum* Smith, *Tropidoneis lepidoptera* (Gregory) Cleve, *Amphora communata* Grunow, *A. robusta* Gregory, *Nitzschia sigma* (Kützing) Smith, *N. spectabilis* (Ehrenberg) Ralfs, etc. increased. In the east, halobionts predominated. In plankton—diatoms *Chaetoceros* spp., dinophytes *Glenodinium berghii*, *Peridinium latum*, *Chrysosporum bergii* (Ostenfeld) Zapomelová, Skácelová, Pumann, Kopp & Janecek and *Gomphosphaeria aponina* remain. Benthic halobionts—diatoms *Achnanthes haukiana* Grunow, *Mastogloia* spp., *Navicula digitoradiata* (Gregory) Ralfs, *Halamphora coffeaeformis* (Agardh) Levkov, *H. veneta* (Kützing) Levkov, *Gyrosigma acuminatum* (Kützing) Rabenhorst, *Tryblionella hungarica* (Grunow) Frenguelli, *N. obtusa* Smith and others appear (Abrosov, 1973).

Lake Balkhash is poor in macrophytes. In it (along with the delta of the Ili River), 35 species of higher plants and seven species of charophytic macroalgae were found. Of them, at salinity <1‰, there are 34 and seven species, respectively. With increasing salinity, their number is decreasing. At 1–3‰, there are 17 and seven species, respectively, and at salinity >3‰, there are only 6 species of higher plants and 1 species of charophytic macroalgae. The causes of poverty in the macrophyte flora in Balkhash are its salinity, water turbidity, the powerful impact of waves on the coast and geographical isolation from other basins (Abrosov, 1973).

The less resistant to water salinity are white water lily *Nymphaea candida* J. Presl et C. Presl, arrowhead *Sagittaria sagittifolia* Linnaeus and duckweeds *Lemna minor* Linnaeus, *L. trisulca* Linnaeus. The most resistant to salinity are reed *Pharagmites australis* (Cav.) Trin. ex Steud., sago pondweed *Stuckenia pectinata* (Linnaeus) Böerner, horned pondweed *Zannichellia palustris* Linnaeus, watermilfoil *Myriophyllum spicatum* Linnaeus, bulrush *Scirpus kasachstanicus* Dobroch., beaked tasselweed *Ruppia maritima* Linnaeus among the higher plants, and among the charophytic macroalgae—*Chara tomentosa* Linnaeus and *Nitellopsis obtusa* (Desvaux) Groves (Abrosov, 1973; Barinova et al., 2017; Krupa, Barinova, Tsoy, & Sadyrbaeva, 2017).

Turbidity of water prevents the development in Balkhash of charophytic macroalgae. They are found only in those parts of lake (mainly in its eastern part), where the water transparency is high (Abrosov, 1973).

As of the shallowing and salinization of Balkhash, the thickets hydrophytes have reduced. If in the past thickets of reeds in Western Balkhash had a width 10–20 km and stretched for 250 km, then the width of these thickets decreased more than 10 times (Abrosov, 1973).

2.2 | Fauna

Due to the geographical isolation, fauna of Balkhash originally was qualitatively and quantitatively poor.

2.2.1 | Zooplankton

In the past, the basis of zooplankton of Lake Balkhash was as follows (Rylov, 1933): ciliates *Codonella cratera* Leidy; rotifers *Synchaeta* spp., *Filinia longiseta* (Ehrenberg), *F. longiseta* var. *limnetica* (Zacharias), *Polyarthra platypiera* Ehrenberg, *Pompholyx sulcata* Hudson, *Keratella quadrata* (Müller), *K. quadrata* var. *valga*, *K. cochlearis* (Gosse), *K. cochlearis* var. *tecta* (Gosse), *Chromogaster ovalis* (Bergendal), *Hexarthra oxyuris* (Zernov); copepods *Arctodiaptomus salinus* (Daday), *Thermocyclops crassus* (Fischer), *Mesocyclops leuckarti* (Claus); cladocerans *Daplinia galeata* Sars (previously it was mistakenly identified as *D. cristata* (Sars) and even was described as a new species *D. balchaschensis* Man.), *Diaphanosoma lacustris* Korinek (formerly defined as *D. brachyurum* Lievin), *Chydorus sphaericus* Müller and *Leptodora kindtii* (Focke). The leading role was played by rotifers and predominating species was *K. quadrata*. Among copepods, the leading form was *A. salinus* more numerous in the East Balkhash. Sometimes the predominant species of crustaceans in zooplankton became *T. crassus*. Widespread, though not numerous, was *M. leuckarti* (Abrosov, 1973).

In the period 1978–1980, the water level of the Lake Balkhash fell, the salinity of its water increased, together with a sharp decrease in nutrient inputs with the run-off of the rivers. It led to significant changes in the qualitative composition and quantitative development of zooplankton. Rotifers *Asplanchna priodonta priodonta* Gosse, *Synchaeta pectinata* Ehrnberg, *Pompholyx complanata* Gosse and *Brachionus* spp., cladocerans *Cephaloxus* sp., *Alona* spp., *Chydorus sphaericus* and *Rynchotalona rostrata* (Koch), copepods *M. leuckarti*, *Acanthocyclops* spp., *Microcyclops rubellus* Lilljeborg and others disappeared almost completely. The main basis of zooplankton abundance and biomass were several species of cladocerans and copepods. Among them, *Arctodiaptomus salinus* and *D. lacustris* are more or less common. Other species of zooplankton, such as rotifer filter-feeders *F. longiseta longiseta*, *Polyarthra* spp., *Keratella* spp. and *H. oxyuris*, were rare. Cladoceran *Daphnia galeata* was recorded infrequently and in small quantities. The numbers of freshwater copepods *Mesocyclops leuckarti* and other cyclopids continued to decrease. In the north-east of the lake, they were found only in the mouths of rivers.

Tendency to reduce numbers of freshwater and brackish-water species of rotifers, cladocerans and copepods was associated with the fall of the lake level due to reduced river flow and, consequently, reduce the input of suspended organic matter and nutrients that stimulate the growth and development of filter-feeding detritophags. As a consequence, the reduction in the numbers of predatory cyclopids also occurred. This was resulting from decreasing in number of their food—filter-feeding detritophags: rotifers *Brachionus* spp., *Euchlanis* spp., *Pompholyx complanata*, *Trichocerca* spp., cladocerans *Chydorus sphaericus*, *Alona* spp. and others.

In the period 1983–1985, due to continuous lake water level fall and salinity increase, significant changes in the qualitative composition and quantitative development of zooplankton occurred. Compared to the end of the 1960s, the total number of species has declined by more than half. Small forms completely fell from the zooplankton: "fine" filter-feeding detritophags—rotifers *Lecane* spp., *Euchlanis* spp., *Pompholyx complanata*, cladocerans from genera *Alona*, *Alonopsis*, *Rhynchotalona* and others. This has led to restructuring of trophic relationships at this level and reduced the numbers of the most valuable species being food for juvenile commercial fish. "Rough" filter-feeders *Diaphanosoma lacustris* and *Arctodiaptomus salinus* began to dominate in zooplankton, but their production possibilities and nutritional value for juvenile fish are relatively low. The number of cladoceran *Sida cristallina* Müller, a typical inhabitant of brackish waters, also increased. The large predatory cladoceran crustacean *Leptodora kindtii* was very rare. Almost everywhere, freshwater cyclopids, the cladocerans *Daphnia galeata*, *Bosmina longirostris* Müller and the rotifers occurred infrequently.

By the end of the 1990s, zooplankton of Balkhash Lake stabilized in quality. Main background was created by rotifers *Brachionus calyciflorus* Pallas, *Euchlanis dilatata*, *Keratella cochleans* var. *tecta*, *K. quadrata quadrata*, *H. oxyuris* and crustaceans *D. galeata*, *D. cucullata* Sars, *Diaphanosoma lacustris*, *Cyclops vicinus* Uljanin, *M. leuckarti* and *Arctodiaptomus salinus*.

Since 1991, the most common biocoenosis (both in pelagic and in littoral zones) in the Lake Balkhash zooplankton is copepod-cladoceran; *A. salinus* and *D. lacustris* dominate in it. The role of rotifers is negligible, although in the 1970s they predominated in numbers over crustaceans. Reducing the numbers of rotifers and cladocerans could be caused by pressure of acclimatized mysids in whose diets these organisms prevail.

In the current zooplankton of Lake Balkhash, 123 species and subspecies of invertebrates have been recorded: rotifers—82, Cladocera—22, copepods (without harpacticoids)—19. But of those only a few are common. Among frequently found rotifers are *Polyarthra dolichoptera dolichoptera* Idelson, *E. dilatata dilatata* Leydig, *K. cochlearis cochlearis* and *K. quadrata quadrata* only. As in the past (Karpevich, 1975; Rylov, 1933; Saduakasova, 1972), among crustaceans four species: *A. salinus*, *Thermocyclops crassus*, *M. leuckarti* and *D. lacustris* are common over all the lake. In Eastern Balkhash, besides them *Daphnia galeata* is common. Another three species: *Leptodora kindtii*, *Ceriodaphnia reticulata* and *Polyphemus pediculus* (Linnaeus) are rare. Near mouths of rivers can be found not numerous species of families Chydoridae and Macrothricidae and species from genera *Eucyclops*, *Microcyclops* and *Macrocyclops* (Krupa et al., 2008, 2013).

It should be noted that specific ionic composition of Lake Balkhash's water—higher concentration of potassium and magnesium (compared to other large saline lakes)—is unfavourable for hydrobionts. Potassium, as well as magnesium, is toxic to living organisms, but their toxicity is weakened by calcium and sodium (Abrosov, 1973; Birshtein & Belyaev, 1946; Chekunova, 1960; Filenko, 1988; Karpevich, 1975; Krupa et al., 2008; Vinberg, 1933). Abundance of planktonic crustaceans in significantly depends on the ratio of ions only in Eastern Balkhash. It decreases with increasing K^+/Na^+ and K^+/Ca^{2+} ratio. Among the dominant species, *Daphnia galeata* is the most resistant to higher potassium concentrations (Krupa et al., 2008).

In addition to the changes in the zooplankton due to the changes in Lake Balkhash abiotic conditions, other important factors constraining the zooplankton development were pollutants and toxic substances. The emissions from industrial enterprises were constantly entering the lake and poisoning aquatic organisms. Apart from industrial pollutants, along the southern shore a large number of agricultural pesticides entered the lake.

2.2.2 | Zoobenthos

Initially, zoobenthos of Balkhash had very poor species composition. Benthic fauna of both western and eastern parts of the lake mainly was represented by larvae of insects (Insecta), especially larval chironomids (more than 30 forms) having forage value for fish. Numerous were larvae of dragonflies (Odonata), mayflies (Ephemeroptera), stoneflies (Plecoptera), caddisflies (Trichoptera; Abrosov, 1973; Karpevich, 1975) and others—aquatic hemipterans and beetles.

Fauna of free-living not abundant nematodes in Balkhash is not studied. Only a few are known about fauna of aquatic mites (Abrosov, 1973).

Oligochaetes are widespread in addition to larval insects. In Lake Balkhash, 9 species of them are known: *Potamothrix hammoniensis* (Michaelsen), *P. bavaricus* (Oschmann), *Limnodrilus profundicola* (Verrill), *L. hoffmeisteri* Claparède, *Tubifex tubifex* (O. F. Müller), *Uncinais uncinata* (Ørsted), *Nais pardalis* Piguet, *Spirosperma ferox* Eisen and *Stylaria lacustris* (Linnaeus) (Abrosov, 1973).

Leeches are represented by three species: *Piscicola geometra* (Linnaeus), *Protoclepsis meyeri* (Livanow) and *Glossiphonia complanata* (Linnaeus) (Abrosov, 1973).

In Lake Balkhash, 6 species of Ostracoda are found: *Ilyocypris* sp., *Candona neglecta* Sars, *Candona* sp., *Darwinula stewensoni* (Brady et Robertson), *Cyprideis torosa* (Jones) and *Limnocythere dubiosa* Daday. Possibly this list is not full because fauna of these crustaceans in the lake is studied insufficiently (Abrosov, 1973).

In the native crustacean fauna of Balkhash, there are only three species of Malacostraca: shrimp *Palaemon superbus* Heller, amphipods *Gammarus lacustris* Sars and, found only in the Western Balkhash, *Dikerogammarus haemobaphes* (Eichwald).

Aboriginal malacofauna of Lake Balkhash consisted only of freshwater species. The only species of bivalves is *Pisidium henslowanum* Sheppard. Among gastropods, there were met: pond snails *Limnaea* *stagnalis* (Linnaeus), *Radix auricularia* (Linnaeus), *R. ovata* (Draparnaud) and *Galba truncatula* (Müller); ramshorn snails *Planorbis planorbis* (Linnaeus) and *Gyraulus albus* (Müller); valve snail *Valvata piscinalis* (Müller); lake limpet *Acroloxus lacustris* (Linnaeus). Some researchers (Tyutenkov, 1959; Zhadin, 1952) also pointed out the presence of *Bithynia caerulans* Westerlund but later this endemic gastropod apparently died out and no longer occurred. In the bottom sediments of Lake Balkhash, shells of extinct mollusc *Valvata cristata* Müller are abundant. The most numerous species of molluscs in the past were *V. piscinalis*, *Planorbis* spp. and *Pisidium henslowanum*.

The spread of native freshwater molluscs in Lake Balkhash is limited. Basically, they live only in shallow waters to the depth of 3–5 m in freshened areas of the lake and in front of the mouths of rivers amid the vegetation on the rocks and under stones. The numbers and biomass of these molluscs are low. Therefore, they have not played any significant role in the diet of fish. The specific ionic composition of salts in the waters of Lake Balkhash and dolomitic grounds at the bottom is considered to be unfavourable for freshwater molluscs (Karpevich, 1975; Samonov, 1966).

In 1953–1966, in order to strengthen forage base for commercial fish, a work was carried out to acclimatize in Lake Balkhash several species of benthic invertebrates. In other water bodies, those are valuable food species. Of the 10 species recommended for introduction, 8 species naturalized successfully. Caspian polychaetes *Hypania invalida* (Grube), *Hypaniola kowalevskii* (Grimm) and amphipod *Corophium curvispinum* Sars were introduced in 1962. In 1958, mysids *Paramysis lacustris* (Czerniavsky), *P. intermedia* (Czerniavsky), *P. ullskyi* (Czerniavsky) and *P. baeri* (Czerniavsky) were introduced from the delta of Volga and the delta of Don. In 1966, bivalve mollusc *Monodacna colorata* (Eichwald) was introduced from the Sea of Azov. Attempts to introduce amphipod *Turcogammarus aralensis* (Uljanin) from the Aral Sea in 1953 and mysid *Limnomysis benedeni* Czerniavsky from the deltas of Volga and Don in 1958 were unsuccessful (Karpevich, 1975).

In addition to these planned introductions, two invertebrates, not being food for fish, were introduced in Balkhash incidentally. In 1957–1958, freshwater bivalves *Anodonta cygnea* (Linnaeus) and *A. cellensis* (Schröter) appeared in the lake because their glochidia were on the gills of introduced from the Ural River zander (Karpevich, 1975).

Currently, 93 invertebrate species, including native and introduced species, are recorded in the macrozoobenthos of Lake Balkhash. In 2009–2013, the main taxonomic group in the benthic fauna is native heterotopic larval and adult insects. However, in zoobenthos the dominant by biomass forms are the introduced representatives of the Ponto-Caspian complex: polychaetes *Hypania invalida* and *Hypaniola kowalewskii*; bivalve mollusc *M. colorata*; malacostracans—mysids *P. intermedia*, *P. lacustris*, *P. baeri*, *P. ullskyi* and amphipod *C. curvispinum*. The large native chironomid larvae *Chironomus* f. l. *salinarius* Linnaeus and *Chironomus* f. l. *plumosus* Kieffer also play a significant role in the formation of zoobenthos biomass.

The composition of benthic fauna differs between the western and eastern parts of the lake. In the more saline eastern Lake Balkhash, the species diversity of zoobenthos is lower than in the west. Currently, the amphipod *D. haemobaphes*, native and introduced molluscs, such as *M. colorata*, do not occur in the east. In addition, the east has less diversity of imago and larvae of insects, except for Chironomida and other Diptera.

Moving from west to east in the Eastern Lake Balkhash, mysids disappear: at first *P. baeri*, then *P. lacustris*, further *P. ullskyi* and finally *P. intermedia*. In the eastern end of the lake, the last species is not found (Alekin, 1984).

Since 1996, the biomass of zoobenthos began to increase sharply in connection with the population growth of mollusc *M. colorata* (Krupa, Slyvinskiy, & Barinova, 2014; Krupa et al., 2013). This mollusc is underutilized by benthophagous fishes as food, especially by carp, for which the commercial stock significantly decreased and its population was represented by individuals of younger ages (Isbekov & Timirkhanov, 2009).

2.2.3 | Ichthyofauna

In Balkhash Lake, only six fish species are native: Balkhash marinka *Schizothorax argentatus* Kessler, Ili marinka *Sch. pseudaksaiensis pseudaksaiensis* Herzenstein, Balkhash perch *Perca schrenkii* Kessler, spotted stone loach *Triplophysa strauchi* (Kessler), plain thicklip loach *Barbatula labiata* (Kessler) and Balkhash minnow *Lagowskiella poljakowi* (Kessler). Three of them—Ili marinka, Balkhash perch and spotted stone loach—are endemics of Balkhash-Alakol basin (Abrosov, 1973; Karpevich, 1975).

The only native fish species of commercial value are both marinkas and perch (Abrosov, 1973; Karpevich, 1975). The Balkhash marinka had commercial value and was found throughout the lake and in the rivers until the mid-1960s but by now it has disappeared from the lake, although it still remains, as spotted stone loach does, only in some rivers. Presently, numbers of Balkhash perch remain small. It is preserved only in some bays of Lake Balkhash, in deltaic lakes of the Ili River and in the Ayaguz River (Mamilov, Balabieva, & Mitrofanov, 2012).

Currently, ichthyofauna of Lake Balkhash itself includes 26 species. In the 20th century, because of human activity, ichthyofauna of Lake Balkhash together with the basin's rivers was replenished by 22 fish species (Karpevich, 1975). The number of fish species in the lake (without rivers) has risen by 20. Most of them were introduced intentionally. Others were introduced incidentally; they were brought in together with intentionally introduced fish or accidentally penetrated into the lake itself.

Colonization of Lake Balkhash by new fish species began without a plan and initially occurred as auto-acclimatization. Some species were introduced despite scientific advice to the contrary. The first invader was carp *Cyprinus carpio* Linnaeus. Originally, it accidentally got into the Ili River from fish pond in 1905 and then appeared in the lake. By the end of the 1920s, carp became main commercial species in Balkhash. Its proportion in catches could reach up to 70%. About 1949, from rice paddies, also accidentally, cultured carp from Karatal River penetrated into the lake. This carp gave hybrids with wild carp (Karpevich, 1975).

Siberian dace *Leuciscus leuciscus baicalensis* natio *kirgisorum* Berg is an auto-acclimatization in Lake Balkhash. Initially, it was brought out from Irtysh to the Ayaguz River where it was discovered in 1928. Later, this fish populated the rest of the river basin and in 1950 appeared in the lake (Karpevich, 1975).

In the 1930s, purposeful introductions of new fish species began. Initially, the species were chosen without any preliminary studies.

In 1931, the Aral barbel *Luciobarbus brachycephalus* (Kessler) was brought into the Ili River from Syr Darya. The barbel quickly penetrated into the lake and settled, but has not formed a large population. Apparently, conditions in the rivers are not good for reproduction and the food base in the Lake was insufficient (Karpevich, 1975). Until recently, the barbel lived both in the Lake and in the Ili River. Currently, it does not meet in the Lake (Mamilov et al., 2012).

In 1933–1934, ship sturgeon *Acipenser nudiventris* Lovetsky was introduced into Lake Balkhash from the Aral Sea. It successfully naturalized, formed a population and became one of the commercial species (Karpevich, 1975). Prior to the construction of the Kapshagai reservoir, the ship sturgeon was widespread throughout the lake and in the rivers Ili and Karatal. Currently, however, it is a rare species (Mamilov et al., 2012).

At the same time, attempts were made to introduce ciscos into Balkhash. In the spring of 1933, an inconclusive attempt was made to introduce (fertilized roe) ludoga cisco *Coregonus ludoga* Poljakov. In the winters of 1933–1935, fertilized roe of Peipsi cisco *C. maraenoides* Poljakov were introduced into the lake. Larvae hatching was achieved and numerous juveniles appeared, but finally this attempt failed. After 1936, Peipsi cisco disappeared, leaving no descendants. Presumably, the demise of the fish was due to consumption of its roe on the spawning grounds by minnows and by inappropriate summer temperatures (Karpevich, 1975).

After a long break, in 1948 acclimatization work on Lake Balkhash resumed. By this time, after preliminary studies the most suitable species for introduction were selected (Karpevich, 1975). However, these scientifically based recommendations were not always followed.

In 1948, tench *Tinca tinca* (Linnaeus) was brought in the Ili River basin from the Zaysan Lake, despite the fact that it was not recommended for introduction (Karpevich, 1975).

In 1949, eastern bream *Abramis brama orientalis* Berg was introduced into the lake and Ili River from Syr Darya. Its acclimatization has been successful, and in Lake Balkhash, bream quickly became an important commercial species. At the same time, bream competes with carp and marinka for food which is insufficient for all species, confirming the correctness of opponents of the bream introduction (Karpevich, 1975).

Prussian carp *Carassius auratus gibelio* (Bloch) was another species not recommended for introduction to Lake Balkhash. It was released in 1954 into the Karatal River from ponds, and it then entered the Lake and settled to become a commercial species (Karpevich, 1975).

The first introduced species from the number of fish recommended for acclimatization was the zander *Sander lucioperca* (Linnaeus). In 1957–1958, the sires were transported from the Syr Darya and Ural River. Acclimatization of this predator was successful due to the presence of suitable spawning areas and food for both juveniles and adults. The number of zander grew fast. In 1963–1964, it has reached the maximum, resulting in an acute shortage of food. By this time, zander had eliminated basic food species—marinka, perch and loach, and it switched to cannibalism and alternative foods. As a result, in 1965 a mass mortality of zander occurred, and in subsequent years, their numbers decreased. This situation resulted from the late development of fishing of zander because of its population number was not controlled to match available food (Karpevich, 1975).

When introducing zander into Lake Balkhash, three more predators were also introduced. In 1957, without any justification the wells *Silurus glanis* Linnaeus was introduced from the Ural River. In 1957–1958, the asp *Aspius aspius* Linnaeus and the Volga zander *Sander volgensis* (Gmelin) were accidentally introduced from the Ural River. These invaders multiplied and by the mid-1960s had become commercial fish species (Karpevich, 1975).

In 1965, despite protests from experts on acclimatization of fish, the roach *Rutilus caspicus* (Jakovlev) was introduced from Bilikol Lake into Lake Balkhash. By this way, one tried to strengthen the food base of zander as a predator during its population explosion instead of bringing the population into accord with food resources by strengthening its fishery. Roach quickly naturalized, populating the entire lake and most of the rivers. Other reasons for recommending against introducing this benthophage were also because it would compete with the more valuable bream and carp. Together with the roach, the Talas dace *Leuciscus lindbergi* Zanin was also incidentally brought into Lake Balkhash. By the 1970s, it settled widely in the western part of the Lake (Karpevich, 1975).

In 1958 and in 1962, recommended herbivorous fishes were also introduced into Lake Balkhash: phytoplanktivorous silver carp *Hypophthalmichthys molitrix* (Valenciennes) and herbivorous grass carp *Cthenopharhyngodon idella* (Valenciennes) (also introduced in 1963 and 1965). For unknown reasons, silver carp did not survive in the basin of Lake Balkhash. Acclimatization of grass carp was successful and huge reserves of plant food provided for its high growth rate. It settled across the lake and entered rivers, mostly in their deltas overgrown with aquatic vegetation (Karpevich, 1975).

Together with the young herbivorous fish (grass carp, silver carp), coarse fish—Chinese freshwater sleeper *Micropercops cinctus* (Dabry de Thiersant)—was introduced accidentally into the Lake Balkhash basin. This invader did not reach high numbers and lives in the tributaries of Ili River ad in its deltaic lakes, as well as in Lake Balkhash (Karpevich, 1975; Reshetnikov, 2010; Seleznev, 1974).

3 | LAKE BALKHASH WATER LEVEL NEARLY REAL-TIME MONITORING FROM SATELLITE DATA

As shown above, there is likely strong linkage between water level of the Lake Balkhash and the fauna living population, distribution and abundance, in the lake. Propastin (2008) has shown that the hydrological regime of the Ili River influences directly the biomass trends in the delta and the water level changes in the Lake Balkhash. They have investigated the dynamic of biomass of the Ili delta in the past and concluded that it was not linked to changes in the atmospheric precipitation, but fully to the variability of the discharge from the river induced by the regulation of the Kapshagay Reservoir. As shown above and in numerous literature (Abrosov, 1973; Imentai, Thevs, Schmidt, Nurtazin, & Salmurzauli, 2015; Krupa et al., 2008, 2013), zooplankton, and zoobenthos composition, distribution and evolution are strongly depending on water salinity, therefore indirectly on the water level of the Lake Balkhash. Consequently, the fish population is also linked to the water level of the lake. It has also been shown by Berezovikov and Zhatkanbayev (2002) and Morimoto, Horikawa, and Natuhara (2008) that the population of birds in the Ili delta is also correlated with the water balance of the Lake Balkhash. Abrosov (1973) has shown that changes in the water level of the Lake Balkhash after the construction of the Kapshagay Reservoir in 1970 have destroyed the habitats and reduced the number of mammals in the Ili delta. Some predictions, based on the evolution of water intake for agriculture in the Balkhash watershed, in addition to potential decrease in the discharge of the Ili River due to climate change are the major threat for the conservation of biodiversity into the Ili delta but also the entire Lake Balkhash basin (Imentai et al., 2015). Prediction is not easy in such a complex system, with several factors of various natures impacting the water resources in the basin, and this will need further research relying on accurate measurements of different variables. It could be inferred from in situ gauges and field work (for river discharge, counting of fauna population) but also on remote sensing satellites for other variables like biomass in the delta, snow cover in the mountain, or water level in the reservoir, the river and the lake itself.

Below we show some results of lake level monitoring (as well as reservoir and the river) using satellite radar altimetry. Crétaux, Biancamaria, Arsen, Bergé-Nguyen, and Becker (2015) have shown that this technique is suitable for water management purpose in the Syr Darya basin which presents some identical characteristics than that of the Ili-Balkhash basin: connection between reservoirs and terminal lake along a river flowing in arid region where both hydroelectricity and irrigated agriculture present economical, ecological and political issues in a transboundary river basin framework.

Since the mid-nineties, satellite radar altimetry has been a widely used for monitoring height variations of continental surface water, such as lakes and rivers (Birkett, 1995; Calmant, Seyler, & Cretaux, 2008; Santos da Silva et al., 2014; and many others). Once a satellite track passes over a lake or a river, the altimetry technique permits systematic water height measurement. Another characteristic of satellite altimetry is its ability to monitor lakes and rivers over decades with a revisit on each target ranging from a few days to a few months depending on the orbit. For example, the Topex/Poseidon, Jason-1, Jason-2 and Jason-3 satellites have a cycle of 10 days, GFO a cycle of 17 days, Envisat and Saral/Altika 35 days, while for Cryosat-2 the revisit cycle is 369 days allowing a very dense coverage of the Earth's surface at a yearly revisit scale. For large lakes, many satellites can pass over them providing continuous monitoring over decades.

Satellite altimetry has some limitations for small lakes since lake-shore topography might affect elevation calculations from the altimeter, but for large lakes, it has been shown (Crétaux et al., 2016, 2011; Ričko, Birkett, Carton, & Crétaux, 2012; Schwatke, Dettmering, Bosch, & Seitz, 2015) that the accuracy is sub-decimetre with such system.

In order to quantify the water balance over a lake, it is however preferred to use the water volume changes, not directly measurable from satellite altimetry. Moreover, the determination of the absolute water volume of a lake is impossible without precise bathymetry (Crétaux et al., 2005; Lei et al., 2014). In such case, satellite multispectral imagery can be used. It allows determining the shoreline delineation of a lake consequently calculating lakes areal extent at different epochs.

The Hydroweb database (http://hydroweb.theia-land.fr) was created by Legos in 2003 and now provides the water level, of 160 lakes worldwide, including the Lake Balkhash and the Kapshagay Reservoir. For some lakes, the water extent and volume changes are also calculated. It also provides the water level along few big rivers including the Ili. Moreover for a selection of 63 big lakes in the world, the water levels are calculated in an operational mode and in near real time. It is the case of the Lake Balkhash and the Kapshagay Reservoir. Their water levels and volume are currently calculated every 2 days (Balkhash: Figure 2) and 10 days (Kapshagay: Figure 3) with the Jason-3 satellite with a latency of 3 days. Combining satellite altimetry data with satellite imagery (Crétaux et al., 2016), Hydroweb provides also the water volume of the Kapshagay Reservoir over a period of 25 years (end of 1992 to end of 2016).

We observe from Figures 2 and 3 that the pluri-annual water level changes in the Kapshagay Reservoir and the Balkhash Lake are very similar: A water level increases from the mid-nineties up to 2004–2005 followed by oscillation of about 5–6 years of period of time. Both water bodies have correlated water level changes over the last 25 years. Indeed, a decreasing (or increasing) water level of the reservoir is also characterized by decreasing (or increasing) of the lake. So the lake Balkhash water level changes are not directly controlled by the release or the storage accumulation in the reservoir, but more likely to environmental changes upstream to the reservoir: less water in the reservoir due to increasing irrigation or dryer climate condition upstream means decreasing of the release to the Lake Balkhash, hence a decrease in its water level. It has moreover been shown (Dostay et al., 2012) that since the construction of the Kapshagay Reservoir, the water losses in the Ili delta have also increased by about 10% and it represents ~26% of the total water flow in the top of the delta. During high winter released of the reservoir, the water losses in the delta have increased proportionally, so this explains also why a high release of the Kapshagay Reservoir is not followed by an increase in the level of the Balkhash Lake.

We have also analysed the water level changes along the Ili River at crossing section between the satellite tracks and the river (called virtual station: VS) using the Jason-2 data (Jason-2 was launched in 2008 so the period is restricted to 2008 to end of 2016 when Jason-2 moved onto a new orbit). We have measured water level changed at 3 VS upstream to the reservoir (Figure 4a–c) and one downstream (Figure 4d). We see from the Figure 4a–d that the long-term changes

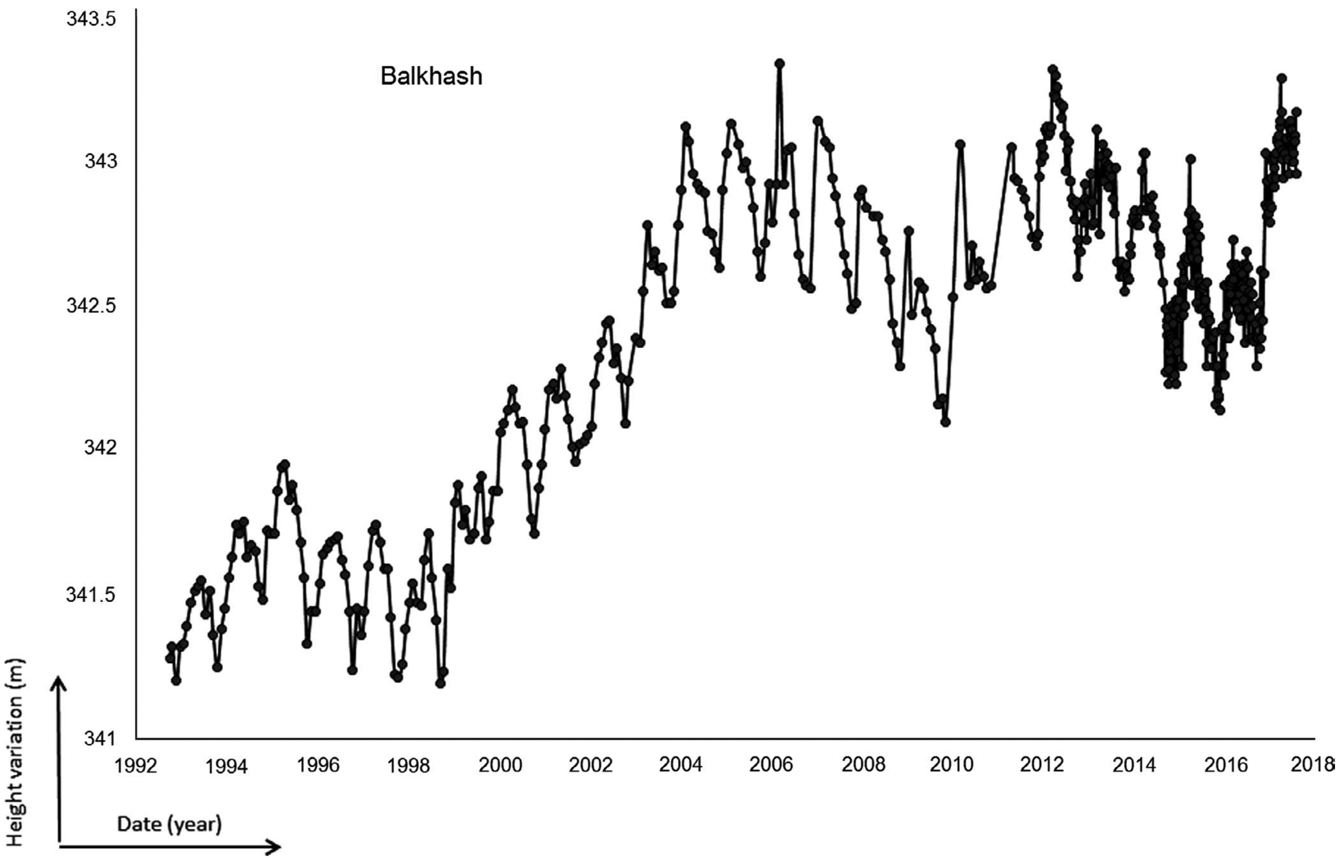


FIGURE 2 Water height change in the Lake Balkhash using of satellite altimeters (Topex/Poseidon, Jason-1, Jason-2, Jason-3, Envisat and Saral/Altika). Extracted from Hydroweb

in the reservoir and the river upstream and downstream are similar and timely correlated. This clearly means that the reservoir water level changes are in priority driven by the upstream changes: an excess of water in the reservoir is followed by an increase in the reservoirs level but also the reservoir release. Therefore, we can conclude from these data that the water stocks released from the upstream part of the Ili River has a strong influence of the water balance of the Lake Balkhash not controlled and compensated by the Kapshagay Reservoir: it enhances the role of precipitation over the Ili watershed in majority over the high elevation region in the upstream part of the watershed located in China, the role of the glacier melt and the role of the irrigation. It has been shown in Kezer and Matsuyama (2006) that from 1970 to 1986, natural variability played the main role in the river run-off variability (~60%) while human activity had a minor although still significant role of 40%. It has been shown that during this period, the main decreased of the river run-off occurred during the growing season (March–September) but also that it has concerned only the mid and lower reach of the Ili River. In a context of increasing irrigation in upper part of the river, this scenario could be totally changed with high consequences on the Lake Balkhash water balance. Only a full water balance analysis assimilating in situ climate variables would allow characterizing the respective role of natural and artificial origin of the changes in the watershed of the Lake Balkhash. It would need exact quantification of run-offs and of the E-P term of the water balance. However, the results shown in Figure 4a–e show that when the inflow to the reservoir is increasing, the water level of the reservoir also increases although the outflow does the same. It indicates that the driver today of the Lake Balkhash is fully linked to the total inflow from upstream part and the role of the reservoir keeps minor.

What is the role of irrigation in the upstream part still remains uncertain and until now not precisely quantified. However, we might see that the lake Balkhash, the Lake Sassykol and the Lake Issyk-Kul that are in the same climatic region have exactly the same behaviour over the period of our study from 2008 to 2016 (see http://hydroweb.theia-land.f for operational nearly real-time water level changes in lakes from satellite altimetry). They however have different policy of irrigation which might lead to think that until now, the major driver of these lakes water level changes remains in high proportion due to climate fluctuations. Situation obviously might change rapidly if irrigation in the Ili upstream part will increase in the future. There is also likely an enhancing feedback of climate variability on irrigation policy, since dry year might be a reason for increasing irrigation and in opposite wet year might lead to contain irrigation to low values.

In a near future (2018–2021), many new satellites will be launched which will allow better quantifying different components of the water cycle over this region. New satellite altimetry with sentinel-3B, Jason-CS/Sentinel-6, Icesat-2 and then SWOT (surface Water and Ocean

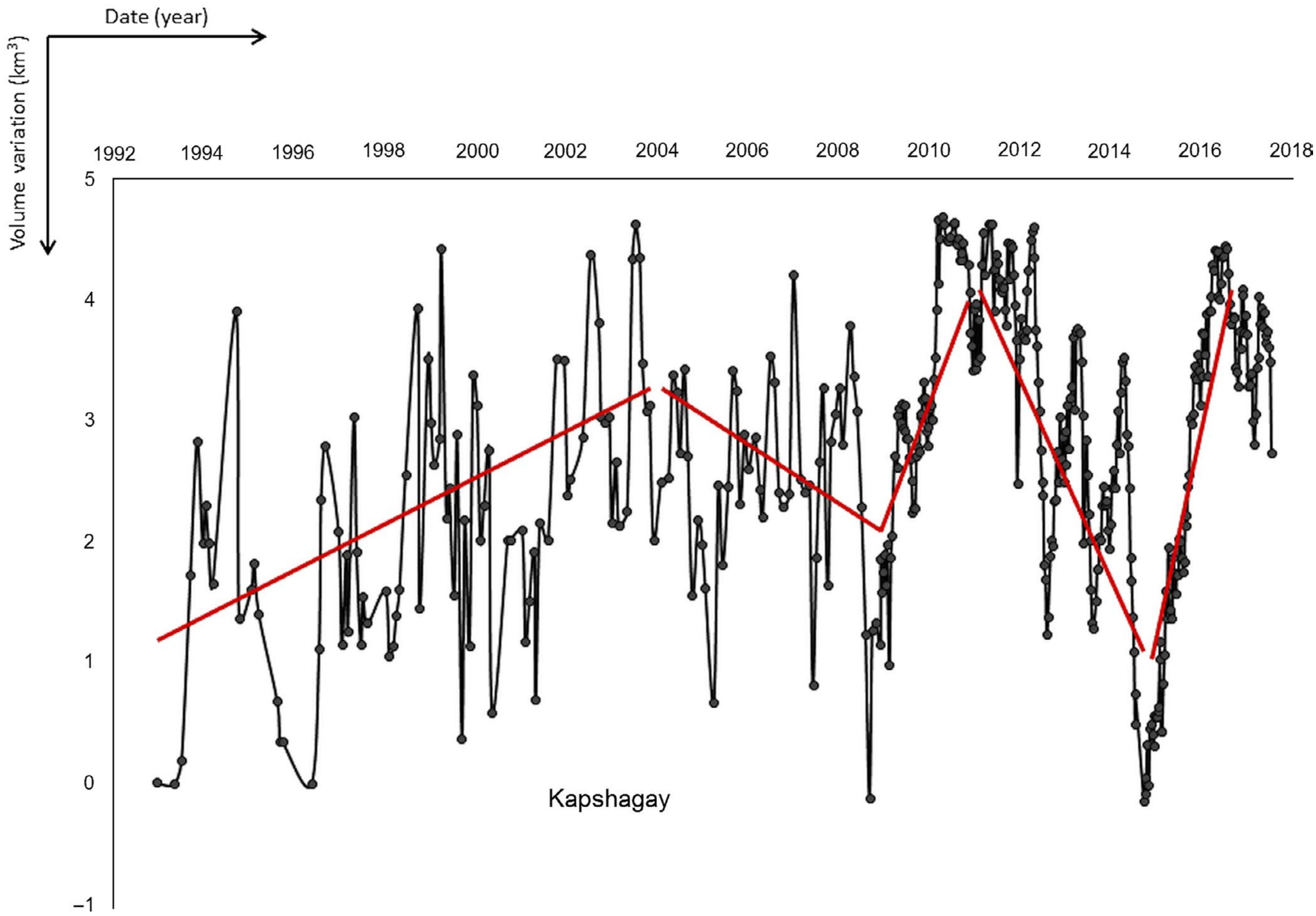


FIGURE 3 Volume change in the Kapshagay Reservoir using combination of satellite altimetry and satellite imagery (red line represents pluri-annual changes). Extracted from Hydroweb

Topography) will allow to fully scan the surface water over the Lake Balkhash watershed: the lake, the reservoir and the rivers with indirect measurements of the Ili River discharge. GPM (Global Precipitation Mission) constellation under deployment will allow determining very precisely the precipitations. Missions like the Sentinel-1, Sentinel-2 and Sentinel-3 with different optical and radar sensors will allow mapping the water bodies in the region and their dynamic (in space and time). Thermal remote sensing instruments on Sentinel-3 will allow characterizing evapotranspiration variables. With operational system of survey like the ones developed in Hydroweb or Globolakes (http://www.globolakes.ac.uk), it will be possible to monitor different components of the water balance in near real time and understand the processes behind the Lake Balkhash water level fluctuations.

4 | PERSPECTIVE ON LAKE BALKHASH EVOLUTION: HOW DOES LEVEL FLUCTUATION IMPACT BIOTA?

It is clear from the satellite results on the lakes, reservoir and river levels that their interannual dynamic is significantly correlated and that changes in the upper Ili River have direct consequences measurable on the downstream part of the basin. From the assessment of fauna and biomasses in the Lake Bakhash, and in the delta of the Ili River, we can consider that relatively favourable state of water resources of Ili River in recent years does not remove from the agenda the question of Lake Balkhash's preservation as a single water body with level of not less than 341 m. Over the last years, we have observed a cycle of 5–6 years of regression and transgression of the lake level by ~50 cm of amplitude. Break of this cycle and possible and noticeable decline in the annual flow via Ili River is not excluded. It depends on the balance between glacier melt increases and increasing of irrigated agriculture in the upstream part of the Ili located in the China territory. The risk to repeat the 1970–1980s scenario is a possibility, which might arise in the case of water withdrawal of increase up to the Yamate gauging station. Simulation shown in Figure 5 highlights the vulnerability of the Lake Balkhash to any additional water withdrawal in the upper Ili. In such scenario, if the water level decreases to the critical threshold of 338.8 m a. s. l. the lake could then be divided into western and eastern stretches. The salinity according to preliminary estimates will reach from 6.0 to 10 g/L for a water withdrawal in the upper Ili of 25%–40% of the river flow.

Reducing the water content of the lake, increasing water salinity would lead to the restructuring of ecological communities,

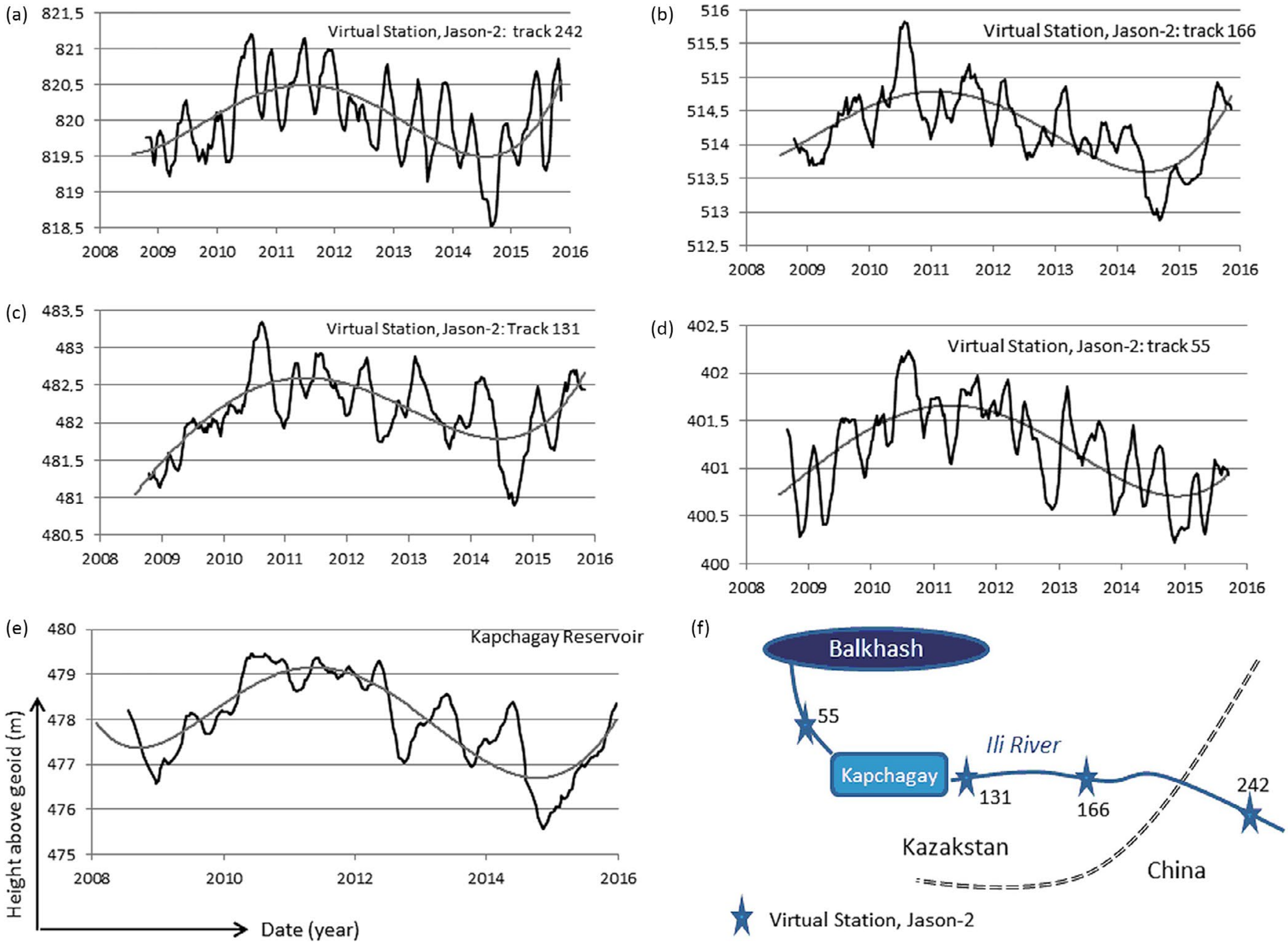


FIGURE 4 (a–d) Water level changes along the Ili River at different virtual stations using the Jason-2 satellite altimeter from upstream to downstream part of the river; (e) water level changes in the Kapshagay Reservoir using Jason-2 satellite altimeter; (f) schematic map of the Ili River representing the position of each virtual station using Jason-2 satellite altimeter

deterioration of conditions of aquatic organisms' reproduction. Increasing salinity of the lake as a result of the alleged withdrawal of prospective Ili River run-off would contribute to reducing the total gross production of phytoplankton and zooplankton. Depending on the chemical water composition, indicators of gross production in the western part of the lake in different types of water intake from the Ili River at different periods of water content will vary from 0.4 to 6.7 million tons; in the eastern part of the lake—from 0.4 to 3.5 million tons, that in turn will affect the quantitative development of zooplankton. Quantitative development of zooplankton could fall from 1.6 to 2.50 g/m^3 in the Western Balkhash and from 0.5 to 1.2 g/m^3 in the Eastern. Reduction of phytoplankton and zooplankton biomass resulting from changes in the water salinity will have a negative impact on the development of zoobenthos feed on small algae and zooplankters. Moreover, the overall decline in trophic would have a devastating impact on fish productivity of the lake (Table 1, Figure 6), since all peaceful commercial fishes feed mainly on benthic organisms. It has been estimated that the fish productivity would

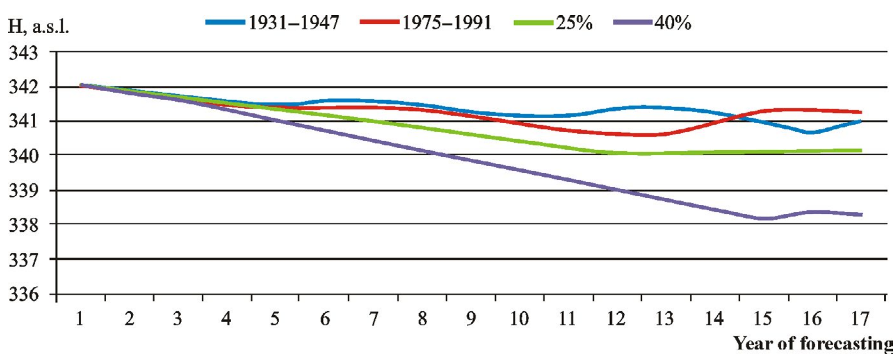


FIGURE 5 Lowering the water level in the Lake Balkhash: natural (1931–1947), during the Kapshagay Reservoir filling (years 1975–1991), at water withdrawal rate of 25% and 40% of the average annual run-off of Ili River

TABLE 1 Calculation of reduced fish catches in Lake Balkhash based on quantity of water withdrawals in China (expressed in percent of long-term annual flow at settlement Yamate)

No. of fishing zone	Area		Annual catch (tons)	Water withdrawals at Yamate					
				20%		30%		40%	
	km^2 (in 2014)	% of lake surface		Area	Catches	Area	Catches	Area	Catches
1	2,226	18.9	2,208	1,606.5	1,594	1,474	1,462	1,315	1,305
2	2,839	24.1	1,383	2,048	998	1,880	915	1,677	817
3	3,334	28.3	1,560	2,406	1,126	2,207	1,033	1,970	922
4	3,381	28.7	1,724	2,440	1,244	2,239	1,142	1,998	1,019
West	11,780	100	6,875	8,500	4,962	7,800	4,552	6,960	4,063
5	643	7.64	425	439	291	411	272	385	255
6	1,372	16.3	873	937	596	877	558	821	522
7	933	11.08	438	637	299	596	280	558	262
8	600	7.13	247	410	168	384	158	359	148
9	1,021	12.12	429	697	293	652	274	611	256
10	987	11.72	331	674	226	630	211	591	198
11	2,865	34.01	263	1,955	180	1,830	168	1,714	158
East	8,420	100	3,006	5,750	2,053	5,380	1,921	5,040	1,799
Lake	20,200	–	9,881	14,250	7,015	13,180	6,473	12,000	5,862

decrease by almost 90% in the scenario of 40% of withdrawal of the Ili River run-off. Even in a less catastrophic scenario, potential additional water withdrawal from Ili River would inevitably affect the fish spawning areas that will be separated from the main water body, then will dry up and gradually become salty swamps. In the freshened western part of the lake, the spawning areas will move after the retreat of the water, but in the eastern part, with higher water salinity following the reduction of the Lake Balkhash area, the spawning areas would be concentrated in the freshwater estuarine areas of the rivers Karatal and Lepsy. The water deficit will also lead to degradation of the Ili delta (Dostay et al., 2012) which will lose most of its value for fishery. The regulation of the Kapshagay Reservoir in winter for hydropower generation also modifies the natural regime of water regime in the delta as shown by Dostay et al. (2012).

Shoaling and swamping of deltaic water bodies would be accompanied by overgrowth with tough vegetation, salinization and growing concentration of humic acids having depressing effect on the growth and development of fish and other aquatic organisms. Sudden changes in environmental conditions in the water bodies of Ili River delta and in the bays of Balkhash Lake would lead to acceleration of natural selection. It would direct towards narrowing phenotypic variance of populations and formation of local populations of slow-growing fish forms as adapted to harsh conditions of new biocenoses. Degradation of Lake Balkhash ecosystem would favour growth of the number of non-commercial and low-value fish species, while the number of fast-growing forms of carp, bream, asp and other commercial species would rapidly decline. Along with other factors, it would lead to sharp decline in fish resources of the lake as a whole.

FIGURE 6 Schematic map of Lake Balkhash division into 11 fishing zones (biotopes)

There is a project to preserve hydrological regime of West Balkhash Lake separating it from East Balkhash by a dam with gateway in the Strait of Uzun-Aral. Thus, the water supply from the western part of the lake to the eastern one would be restricted. In other words, it is proposed to sacrifice the eastern part of this unique lake and to transform it into shallow highly mineralized water body.

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