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Chapter 15

Implication of Alien Species Introduction to Loss of Fish Biodiversity and Livelihoods on Issyk-Kul Lake in Kyrgyzstan

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Additional information is available at the end of the chapter

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1. Introduction

Lake Issyk-Kul in Kyrgyzstan is the second largest mountain lake in the world (after Lake Titicaca in South America). It is situated in a basin surrounded by high mountains. While its water level is at 1608 m altitude, the mountain ranges of Kungei Ala-Too in the north reach 4711 meters, and those of Terskei Ala-Too in the south 5216 m. These mountains represent the major part of the Issyk-Kul catchment of 22,080 km^2 and provide most of the water to the lake.

Issyk-Kul Lake is 180 km long and 60 km wide, its surface area is 6240 km^2, and the shoreline 670 km (Figure 1.). The mean depth is 280 m, and the maximum 702 m, making it the fifth deepest lake in the world. The area covered by a depth of 0-100 m represents 38% of the total area. This is the major production zone of the lake [1].

Native fish stocks in this high-altitude saline lake have been subjected to predatory pressure from large number of introduced alien fish species. Previous papers and fishers are convinced that these predators are the most destructive to fish biodiversity in the lake, but this study wants to raise also other reasons which could explain at least part of the loss of fish stocks. The rapid growth in human activities with the development of tourism industry; irrigation; water eutrophication and pollution, and climate change impacts are alternative factors this presentation focuses on. This chapter also reviews the fish stocks and fishery management measures to increase the fish yields at the Lake.

Measures taken in order to protect the decreased fish stocks and endemic fish species include a Moratorium for Artisanal and Commercial Fish catching for a period of 10 years (2003-2013). Despite of the Moratorium at least 500 people continue their activity as illegal fishermen. Impacts of illegal and over-fishing are evaluated as anthropogenic activities. It is

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also noted that the disintegration of the Soviet Union had profound economic and social effects on many of the newly independent transition economies, like Kyrgyzstan.



Figure 1. Lake Issyk-Kul is large like a sea. Opposite shore is often not visible. Photo: Azat Alamanov

2. Description of study region

2.1. Physical and chemical environment

Although located at a high altitude, Issyk-Kul Lake never freezes over. The water temperature does not fall below the temperature of maximum density (2.75 ^{o}C at the mineral concentration of 6‰) except in shallow Rybachinsky and Tyup bays. The climate is continental with a short hot summer and a cold long winter. In summer the surface water temperature in the central part reaches 18^{o}C, in winter it is seldom above 4^{o}C [2]. The temperature may drop by 12-14^{o}C down to 50 m depth and a further 1.5-2^{o}C to the depth of 100 m. The water layer at 100-200 m depth maintains almost a stable temperature with changes kept within 0.1-0.3^{o}C [3].

The chemical composition of the lake is as follows in mg/l^{-1}: Calcium – 121, Magnesium – 287, Sodium+Potassium – 1544, Chloride – 1596, Bicarbonate+Carbon trioxide – 318, Sulfate – 2102. Total cations: 1952, total anions 4016 [4]. So its mineral content is

chloride/sulfate/sodium/magnesium based. With the drop in water level also comes a certain increase in salinity. Data from 1932 shows that the salinity measured 5.8‰, and by 1984 it had increased to 6.0‰. Over this period water level dropped by 2.5 m. Current measurements show that the salinity between October 2008 and November 2009 varied in Bosteri between 2 and 9‰ and the average was 5.9‰; which indicates that it is going down (Mikkola, unpublished). Since 1986, the decline in water level has stopped and the lake level has started to rise again. Low salinity (less than 20% that of seawater) indicates that in historical terms Issyk-Kul has only relatively recently become a closed lake. Hydrologists have suggested that, deep underground, the lake water filters into the Chui River. It looks as though the river Chui never "found" its way to the lake as the river bends a mere 4 km of the lake to the west, disappearing into the desert of Kazakhstan. During the very high water cycles the lake's water may overflow to the river through a natural depression – the Kutemaldu channel.

Currently the pH ranges between 7.7 and 7.9. The waters of Issyk-Kul are rich in oxygen, as a result of aeration and movement of lake waters. First of all, water is well oxygenated because it is regularly mixed by strong winds. During the warm period of the year, the surface water moves from the central part of the lake towards the shores and it is replaced by deeper cool water. In the middle of the lake the water is stratified down to 5-10 m whereas near the shores the thermal discontinuity is at a depth of 20-30 m owing to the warm water inflow. Apart from the central upwelling there is also lateral upwelling that is, caused by the wind driving surface water from the shore to the open parts of the lake [5]. Two major currents, driven by two wind streams, can almost always be observed: one follows the northern shore in a westerly direction, and the other flows east along the southern shore. The transparency of Issyk-Kul waters approaches that of seawater, and in the open part of the lake Secchi disc readings range from 30-47 m, but are reduced even down to 50 cm at the mouths of the inflowing rivers.

2.2. Biological features

Lake Issyk-Kul flora contains emerged macrophytes, like *Phragmites australis, Typha latifolia* and *Scirpus tabermaemontani* until the depth of 1.5 m. Submerged macrophytes like *Potamogeton pectinatus, Myriophyllum spicatum* and *Najas marina* and attached algae can go down to 30-40 m. Mean annual macrophyte production is about 277 g/m^2 [6]. *Characeae* are the most common macrophytes, representing 96% of the total annual macrophyte production, and are present in almost all plant associations. Four species of *Chara* grow in shallow water, and three benthic species exist further down. Dense growth of *Charophyte* green algae extends to 40 m depth. Issyk-Kul Lake water is rich in phytoplankton, with 299 identified species. Blue-green algae (*Cyanophyceae*) dominate, but their standing crop is low [7]. Phytoplankton production is at the level of 49 g/m^3 [6].

Zooplankton includes 117 species and is dominated by *rotifers* (84%), followed by *cladocerans* (9%) and *copepods* (7%). Zooplankton production is 91g/m^3 [6]. Zooplankton and phytoplankton distribution in the lake is uneven, with bays and shallows being richer than

open water. *Arctodiaptomus salinus* is present in all parts of the lake and over the year it may represent 75-95% of the total number of zooplankton and 95-99% of the biomass. This species migrates during the night into the surface water where its concentration reaches up to 35,000 ind/m^3 [8], thus representing an important food source for all plankton-eating fish like Issyk-Kul Dace *Leuciscus bergi.*

Zoobenthos comprises 224 species. Most benthos occurs between the shoreline and 40 m depth, which comprises the *Charophyte* zone. According to [6] the mean annual production of zoobenthos is 10 g/m^3. It has been calculated that the average biomass of zoobenthos in the gulfs with open zones is 93.6 kg/ha [9]. *Chironomids*, mollusks, *gammarids* and *Mysis* comprise 75-80 per cent of the total. In the deeper zone beyond the zone of *Characeae* and down to about 70 m, the biomass is 2.5-3.5 g/m^2 and is dominated by *chironomids* and the mollusk *Radix auricularia*. Three *Mysis* species introduced into Issyk-Kul from Lake Balkhash, Kazakhstan, in 1965-1968 are now permanently established in shallows, mostly in 1.5-1.8 m depth, but reaching down to 10 m. Their mean biomass in such waters has been measured to range from 1.5 to 2.5 g/m^2 [10].

2.3. Distribution and abundance of fish fauna

The original fish fauna comprised twelve indigenous species and two subspecies particular to this lake (Table 1). The long historical and geographical isolation of the lake favoured the formation of endemic forms. This fauna is a typical example of the local Central Asian fish complex originating from Central Asian Mountain fauna (a term used by Berg, 1949), which is characterized by the presence of the *loaches* and *cyprinids*, with a small addition of *leuciscins* of Siberian origin. In the native fish fauna of the lake there were no predators although large Naked Osmans *Gymnodiptychus dybowskii* are said to feed partly on small fish [11].

Strictly endemic fish Schmidt's Dace *Leuciscus schmidti* is present throughout the shallow littoral zone but goes during winter down to 35-40 m. It appears in two forms, a common fast-growing lake form and a slow-growing bay form. The fast-growing form reaches 31 cm, a weight of 650 g, and age of 11 years. It spawns on stony beds at depths of 0.5-10 m between the end of March (water temperature 5°C) and mid-May. Fecundity is 6,000-65,000 eggs per year. It feeds largely on *Characeae*, but also on mollusks. The slow-growing form is present throughout the shallows. It reaches a length of 23 cm, a weight of 220 g, and a maximum age of 13 years. It has a similar fecundity and it spawns on the same substrate as the other form, but later.

Issyk-Kul Dace was the dominant fish until 1997, when Schmidt's Dace became for the first time the most numerous commercial fish in the lake. Issyk-Kul Dace inhabits the whole littoral zone, but is more pelagic than Schmidt's Dace. During the winter it is found down to depths 120-150 m, and reaches a maximum body-length of 17.5 cm and weight of 60 g. It spawns in shallow waters at depths between 1-8 m, and feeds mostly on plankton. During recent years the number and distribution of this species have sharply declined.

There are two endemic species distributed in mountain waters of Middle and Central Asia. The Scaly Osman *Diptychus maculatus* inhabits high-mountain streams, but enters also into Lake Issyk-Kul. It can grow 50 cm long and weighs up to 1 kg. It feeds on vegetation and invertebrates. The fish spawns in the spring and summer. It has a dwarf form, which lives mainly in the incoming small rivers, and may not live in the lake. It does not exceed 25 cm in length and weighs less than 200 g.

The Naked Osman is found in mountain rivers and lakes (Figure 2.). It also appears in two forms: one inhabits in rivers and the other in lakes. Lake living fish appear to have two ecological morphs: a winter lake morph and a summer migratory morph which spawns in rivers with a sandy bottom. Forms and eco-morphs would indicate that taxonomic studies are needed. The winter morph spawns from February to April and its fecundity is 13,000-14,500 per year. The summer morph is smaller, has a lower fecundity of 5,500-12,000, and spawns from April until September [12,13]. Both morphs are omnivorous. In the lake it feeds mostly on mollusks over muddy and loamy bottoms at 15-30 m deep. The largest Naked Osmans in the lake attain the age of 20 years and can grow up to 60 cm long and 3 kg of weight. It was once important commercial fish in the Issyk-Kul Lake, but there are indications that it is close to extinction [14].



Figure 2. The first Naked Osman captured alive 2009 in the UNDP/GEF Project. Photo:Azat Alamanov

Scientific name	Common name	Indigenous	Introduced
Onchorhynchus mykiss	Rainbow Trout		+
Salmo ischchan	Sevan Trout		+
Coregonus lavaretus	Common Whitefish		+
Coregonus widegreni	Valaam Whitefish		+
Coregonus autumnalis	Baikal Omul		+
Leuciscus schmidti	Schmidt's Dace	e	
Leuciscus bergi	Issyk-Kul Dace	e	
Phoxinus issykkulensis	Issyk-Kul Minnov	e	
Tinca tinca	Tench		+
Gobio gobio latus	Issyk-Kul Gudgeon	e	
Schizothorax pseudoaksaiensis issykkuli	Issyk-Kul Marinka	e	
Diptychus maculatus	Scaly Osman	e	
Gymnodiptychus dybowskii	Naked Osman	e	
Alburnoides taeniatus	Striped Bystranka		+
Abramis brama orientalis	Oriental Bream		+
Cyprinus carpio	Common Carp	o	
Ctenopharyngodon idella	Grass Carp		+
Hypophtalmichtys molitrix	Silver Carp		+
Carassius auratus auratus	Goldfish		+
Pseudoraspora parva	Stone Moroko		+
Capoeta capoeta capoeta	Transcaucasian Barb		+?
Triplophysa stoliczkai	Tibetan Stone Loach	e	
Triplophysa stoliczkai elegans	Tyanschan Loach	e	
Triplophysa dorsalis	Grey Loach	e	
Triplophysa strauchii strauchii	Spotted Thicklip Loach	e	
Triplophysa labiata	Plain Thicklip Loach		+
Triplophysa ulacholicus, including T.u. dorsaloides	Issyk-Kul Naked Loach	e	
Sander lucioperca	Pike-perch		+
Micropercops cinctus	Eleotris or Odontobutid		+
Glyptosternum reticulatum	Turkestan Catfish	e	
Aspius aspius	Asp		+?
Coregonus albula	Vendace (Ryapushka)		+?
Coregonus peled	Peled		+?

e= Indigenous, += Introduced, o= not known if indigenous, and +?=not known if the introduction failed

Table 1. List of fish species in the Issyk-Kul Lake [15].

Issyk-Kul Lake and incoming rivers have five indigenous and one alien loach species which are common in littoral underwater meadows, but are also found down to 100 m depth. They feed on benthos, plankton and eggs of other fish [13]. They have never been recorded by name in the catch of the lake except maybe in the "others" component. Subspecies would urgently require taxonomic revision, especially *Triplophysa ulacholicus versus Triplophysa u. dorsaloides* which are here synonymized.

The Issyk-Kul Gudgeon *Gobio gobio latus* spawns in June-July in shallows and feeds on benthos, detritus and fish eggs. It is preyed upon by Spotted Thicklip Loach *Triplophysa s. strauchii*, Sevan Trout *Salmo ischchan* and Pike-perch *Sander lucioperca* [13]. Again this fish has no commercial value and falls into "others" category in fish statistics.

Issyk-Kul Minnov *Phoxinus issykkulensis* is one of the strictly endemic fish species of Issyk-Kul Lake, but unfortunately there is no data on biology or abundance as it has never been important in commercial fishery.

Common Carp *Cyprinus carpio* is a widespread freshwater fish which has been introduced from Asia to every part of the world and it is included in the list of the world's worst invasive species. Many people in Kyrgyzstan, however, see Common Carp as indigenous calling it 'wild form' of Common Carp (Sazan). Most likely it was also introduced into the lake, but probably during the ancient times. It was known to be cultured in Kyrgyzstan at least since 1852 [15]. If accepting the 'wild origin' then the Issyk-Kul populations can be considered vulnerable to extinction.

Issyk-Kul Marinka *Schizothorax pseudoaksaiensis issykkuli* is an endemic species, which reaches 70 cm and a weight of 8 kg, and spawns from May until mid-July on rocky substratum in shallows near aquatic plants (Figure 3.). Its fecundity is 25,000 per year. It is omnivorous. Between 1985 and 1989 it formed 6% of the fish catch but after 1992 it disappeared completely (Table 2).

3. Background and historical overview

3.1. Introductions of alien fish species

At least 19 species have been introduced to the lake by humans, either on purpose or accidentally. Introduction of Vendace *Coregonus albula* and Peled *Coregonus peled* failed, and also survival of Asp *Aspius aspius* and Transcaucasian Barb *Capoeta c. capoeta* is doubtful as these species have not been reported recently. Formerly, the small Issyk-Kul Dace was the major item in fish catches, where it represented about 90% of total biomass. It was, however, considered to have a low value and this led to a proposal to introduce new fish species into the lake [16]. The introduction of the Sevan Trout from Armenia was recommended and, in 1930, 755,000 fertilised eggs were released, followed in 1936 by a further 800,000. Until 1964 Sevan Trout remained rare in the lake due to the shortage of suitable spawning grounds (Figure 4.). At its best, 1976 and1979, 51,6 and 53,8 tonnes of Sevan Trout were captured from the Issyk-Kul Lake. This was mainly due to state owned hatcheries which released 79 million fry into the lake during the 1970s [17].



Figure 3. One of the few Issyk-Kul Marinka captured alive during the study 2008-2011. Photo: Azat Alamanov

Fish species	1955-1964	1965-1969	1970-1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2003
Schmidt's Dace	482	225	**544**	496	292	241	223	105	44
Issyk-Kul Dace	9586	**10741**	9147	5736	1123	1064	790	94	12
Issyk-Kul Marinka	**263**	39	16	3	34	138	1	-	-
Osmans*	**114**	10	13	17	10	10	19	-	-
Common Carp	75	**85**	29	5	7	32	22	-	-
Whitefish	-	-	1	35	106	**248**	163	57	11
Sevan Trout	0.3	30	123	**457**	244	206	91	29	1
Pike-perch	-	287	**1364**	895	340	320	227	25	1
Others	46	51	51	15	15	48	98	74	12
Total	**10566**	**11468**	**11288**	**7659**	**2171**	**2307**	**1634**	**384**	**81**

Original data from Fisheries Department/Mairam Sarieva. Note that the data is in centners of Soviet Union. One centner is 100 kg not one ton as so often misquoted in previous publications. *Osmans = Scaly- and Naked Osman

Table 2. Fish catch from the Issyk-Kul Lake in five year averages from 1955-2003.



Figure 4. Sevan Trout is a colourful fish which grows well in the Issyk-Kul Lake. Photo: Azat Alamanov

Following its introduction, Sevan Trout became an active predator of other fish in the lake and developed several special features. Its growth rate was 4 to 6 times that in Sevan Lake in Armenia. In Issyk-Kul it grows to a bigger size. It matures earlier, and its fecundity has increased five-fold to 3,300-17,300 eggs per fish. The limiting factors for this species in Issyk-Kul are food resources and habitat for reproduction.

In the 1950s, there were further introductions of fish species in order to establish diverse stocks of piscivorous fish, introduce species feeding on phytoplankton and aquatic *macrophytes*, and increase the number of benthos- and plankton-feeding fish [18]. Pike-perch, Tench *Tinca tinca* and Oriental Bream *Abramis brama orientalis* were introduced in 1954-1956 [19]. They became established predominantly in the eastern part of the lake but started soon spreading all over the lake. The introduction of Grass Carp *Ctenopharyngodon idella* and Silver Carp *Hypophtalmichtys molitrix*, and with them inadvertent introductions of Goldfish *Carassius a. auratus*, Stone Moroko *Pseudoraspora parva* and Eleotris *Micropercops cinctus*, were successful but caused a disaster to 'wild carps'. Grass and Silver Carp brought infectious *ascites* of carps into the lake, and the numbers of 'wild carps' started to decrease due to disease.

In the early 1970s, a decision was taken to transform the lake into a trout-whitefish water body at the expense of the local Issyk-Kul Dace population. However, Whitefish *Coregonus*

lavaretus is mainly a plankton and benthos feeder, but large individuals can occasionally take other fish. Common Whitefish was introduced from Lake Sevan, Valaam Whitefish or Ludoga *Coregonus widegreni* from Lake Ladoga, and from Lake Baikal came Arctic Cisco or Baikal Omul *Coregonus autumnalis* and Peled [20]. Eggs of Whitefish from Sevan Lake were transferred to the Ton hatchery from which four-day-old fry were released into Lake Issyk-Kul. During 1966-1973 87 million fry were released. In 1974, the first 500 kg of Whitefish were harvested from Tyup Bay.

There were also proposals to replace the Issyk-Kul Dace with the Peled and Vendace (Ryapushka), more nutritious food fish species. However, Peled and Vendace soon disappeared from the lake most likely due to lack of suitable reproduction conditions. Baikal Omul was still observed in the lake as of late 1970s. After that only Whitefish established itself as commercial fish and the highest catch recorded was 35.3 tonnes in 1989. After that the catch started to go down mainly due to reproduction problems and hatchery failure (Table 4).

Most harmful introduction took place accidentally from the cage culture of Rainbow Trout *Onchorhynchus mykiss* (Figure 5.). Since 1980s a lot of small and some large fish started to escape from the culture operations, and now Rainbow Trout is very common all over the lake, but especially near eight cage culture farms. Rainbow Trout moves to fish diet at the size of 35-40 cm [21]. It is not clear if Rainbow Trout would be able reproduce in some incoming rivers, as nowadays the lake seems to have all aged and sized Rainbow Trout.

3.2. Introduction of alien food species for fish

The fish food base was successfully enriched by the introduction of *mysids*, which became targeted by the introduced *coregonids*. In the Issyk-Kul Lake the introduced Whitefish benefitted most of mollusks and *mysids*. Their growth rate was faster than that of the original stock in Lake Sevan, and they also started maturing at an earlier age. However, there was a high mortality of *coregonid* fry which found insufficient food in Issyk-Kul Lake and were heavily preyed on by the endemic fish. Also, it was believed that the higher salinity of Issyk-Kul as compared to Sevan and Baikal could have had a negative impact on fry [20]. The decision was made to stock advanced fry and fingerlings, of which millions were stocked in the following years (at least 10 million from 1977to 1988).

3.3. Recreational and commercial fishing activities

Amateur fishing in the lake started in the 1870s. At first it was unorganized and no statistics were collected. During the 1890s fish catch ranged between 17 – 105 tonnes [2]. At that time, and for many years after, the major commercial fish were Naked Osman, Common Carp, Issyk-Kul Marinka, Issyk-Kul Dace and Schmidt's Dace. According to available information in 1941-1945 harvests of Issyk-Kul Marinka, Naked Osman and Common Carp reached 61 tonnes per year. During the same period Issyk-Kul Dace catch varied from 551 to 900 tonnes per year. It is important to note that during this period lake had already one alien predator, Sevan Trout, but catch of these had not started. It is also interesting to note that 'native' species did not start to go down after the introduction of Sevan Trout [11].

More detailed catch statistics are available from 1955 until the moratorium in 2003 (Table 2). As Table clearly illustrates, fish landings shrunk sharply after the Issyk-Kul Dace population collapsed. Increased fishing activity could be one explanation, but by the end of the Soviet period the state fishing industry was at its peak and encompassed only 300 fishers, 122 boats and 8640 nets [11]. This number of fishers is not much for that size of lake, and over fishing hardly explains alone the decline of fish catches. However, by 1990 Issyk-Kul landings were barely twenty percent of the levels recorded a quarter of a century earlier.

Introduction of one more predator, Pike-perch, into the lake 1954-56 had no immediate and dramatic impact on both lake landings and the species composition of landings. It seems that the production of the lake went down clearly only 1975 onwards, as in the transition from one feeding level (plankton and benthos feeders) to another (predatory fish); the lost feed coefficient against the productivity is approximately ten times. The Pike-perch production reached its peak in 1974, and then the production of Issyk-Kul Dace started to go down very fast as shown in Table 2. The role of Sevan Trout is not as clear as it achieved the highest population only in 1979 after Issyk-Kul Dace had already diminished to one third from the starting level.

Whitefish is often listed as predatory fish but its possible bad habits are not showing clearly in this material. Whitefish achieved the peak population in 1989 when all other species had started to go down very rapidly. Interesting is that the peak populations of Osmans occurred already 1961-62, when all predatory species recorded zero catch. Issyk-Kul Marinka had the peak population in 1988. Total disappearance of Osmans from the catch data happened 1988 and that of Issyk-Kul Marinka 1993. Disappearance of Common Carp took place during the same year (1993) as that of Issyk-Kul Marinka. The predators alone cannot explain these losses, and it is difficult to see any direct relation with fishing either.

Issyk-Kul Dace made 94 per cent of the catch in 1965-69 and less than 15 per cent in 2000-2003, same time the total catch of the lake went down from 1147 to 8 tonnes. Issyk-Kul Marinka, Naked Osman and Sazan Carp are those commercial and indigenous species which are most seriously endangered.

3.4. Fishing as livelihood

The contribution of fishing to annual average income of Issyk-Kul district families is from 5 to 10 per cent and only for some small groups up to 30%. The monthly income of fishermen is not more than 40 USD and that of women processing the fish 54 USD. Women's income is little higher than men's [22]. Although income from fish is small, it allows the families to have cash on daily basis and facilitates implementation of other cash requiring activities (purchase of seeds, forage for animal-breeding etc.). For more details see [15].

3.5. Water level

In historical terms the water level of Issyk-Kul Lake has obviously fluctuated. Some changes are gradual, others sudden and disastrous since they were caused by earthquakes and

torrents of water rush from mountains. Large ancient city has been located at depths of 5 to 10 meters near the north coast of the lake, but it was destroyed maybe some 2500 years ago by one of the many local floods which are known to occur every 500 to 700 years [23]. Between years 600 and 1200 AD Issyk-Kul shoreline was again some 500 m lower and after that in the fifteenth century the water level of the lake was more than 10 m higher than it is today.

On Issyk-Kul basin118 rivers and streams flow toward the lake, but only 42% of them actually drain into it and 25% have discharges less than 1 $m^3 s^{-1}$. Only 9% of these are rivers with catchment areas of more than 300 km^2. Rivers are fed predominantly by melt water from glaciers and snow above 3300 m. The river system reflects also the distribution of rainfall in the basin with low precipitation in the west, where the river system is poorly developed. In the east, where the precipitation is heavier, the hydro-network is denser and the rivers fuller. The greatest volume of flow comes through rivers on the basin's eastern side. Water from most of the rivers has been completely diverted for irrigation before it enters the lake. Therefore, bays in the northern and western coast suffer from increased mineralization. The rivers supply the lake with 3720 million m^3 of water per year [24], but they are not the only water supply the lake is receiving. The annual surface water discharge, precipitation and groundwater discharge to the lake are 21, 29, and 33cm respectively; the evaporation from the lake is 82cm. For more details see [7].

Until 1985 water level in Issyk-Kul was falling. Between 1876 and 1972 the decrease was 9 m [25]. During 1960-1979 when the fish catches started to decrease clearly the total decline of water level was 140 cm, at an average rate of seven cm annually. That loss of water level has been one important factor affecting the fish stocks and fisheries.

3.6. Irrigation

Uptake of water for irrigation is one of the factors seen to be responsible for the present changes in the water level. Irrigation also hinders the river spawning of many species, as it prevents small rivers and streams from reaching the lake. Irrigation has led to drying and silting up of spawning grounds and death of the fry themselves as they are poured out with the river water to irrigated fields. During 1960-1979 irreversible uptakes of water from rivers for irrigation reduced the volume of river water entering the lake by an estimated 23 per cent [6]. While in 1930 there were 50,000 ha of irrigated area in the Lake Issyk-Kul catchment, by 1980 the irrigated area reached 154,000 ha [26]. However, even without this irrigation loss, the lake would still have declined at the rate of five cm annually between 1960 and 1979 [27]. This would indicate that climatic factors have also been involved in the fall of the water level.

4. Material and methods

This chapter is based on my field work and data collection in Kyrgyzstan when working in the UNDP/GEF Project: "Strengthening policy and regulatory framework for mainstreaming biodiversity into fisheries sector" as International Fishery Policy Adviser 2008 to 2009 and in

the FAO Project GCP/KYR/003/FIN: "Support to Fishery and Aquaculture Management in the Kyrgyz Republic" 2009-2010 as Technical Advisor. A lot of generally unknown 'grey literature' in Russian has been translated and used in this text. More information about interviews and field experimentation is documented in [15].

5. Results and discussion

5.1. Species introduced

It is obvious that Sevan Trout and Pike-perch introductions can be blamed for the reduction in catch. There is clear positive correlation between Sevan Trout and Pike-perch and Schmidt's Dace catch (Table 3). Interestingly Sevan Trout has correlation also with Pike-perch catch. There is positive correlation between prey species, like between Marinka and Osmans as well as between Issyk-Kul and Schmidt's Dace and Sazan Carp, but only Whitefish has strong negative correlation with Issyk-Kul Dace.

Species	Pike-perch	Sevan Trout	White-fish	Marinka	Osmans	Issyk-Kul Dace	Schmidt's Dace	Sazan Carp
Pike-perch	1	,535	-,056	-,176	,088	,268	,559	-,012
Sevan Trout	,535	1	,311	,013	,036	-,136	,339	-,193
White-fish	-,056	,311	1	,143	-,316	-,574	-,209	-,149
Marinka	-,176	,013	,143	1	,492	,116	,124	-,288
Osmans	,088	,036	-,316	,492	1	,480	,424	,261
Issyk-Kul Dace	,268	-,136	-,574	,116	,480	1	,622	,468
Schmidt's Dace	,559	,339	-.209	,124	,424	,622	1	,065
Sazan Carp	-,012	-,193	-,149	,288	,261	,468	, 065	1

Red marked numbers correlation is significant at the 0.01 level (2-tailed). Green marked have correlation at the 0.05 level.

Table 3. Correlations of main fish species in the catch between 1955 and 2003.

But correlation does not necessarily mean causation. This far the introduction of predatory fish species has been seen as the major if not the only reason why native fish stocks collapsed [11,15,28]. This same conclusion was also made in Africa, where introduction of the Nile Perch *Lates niloticus* was believed to have caused the greatest vertebrate mass extinction in recorded history [29,30]. Approximately 150 different species of *Haplocromis* chicklids became extinct in recent times in Lake Victoria. Now, however, reevaluated data shows that Nile Perch did not really succeed until, and after, its prey (the *haplochromines*) had disappeared. The increased eutrophication of the lake and oxygen problems may explain more the diversity changes than the single species predation or fisheries exploitation [31,32].

This does not mean that one should support the alien introductions, and precautionary principles are necessary. Precautionary principle states that one has to expect that new introduced species, although in closures or in the cage, tend to escape for one reason or another into nature [33]. Any new voluntary alien introduction should be understood with that background and the rule should be clear: that new human introduced alien species are not allowed to enter into the country. Still it remains inevitable that some invasive species will arrive without any help of humans.

As shown in Table 4 there are seven clear reasons which could explain the loss of fish stocks and biodiversity and another five reasons which have had at least some negative impact. The reviews and field work highlights that all these twelve negative factors have been present more or less at the same time, so it is not possible to single out any one of them as the most important. Surely they have rather caused the loss of fish stocks and biodiversity together. Some of these factors have been listed already before, like over fishing, disintegration of the Soviet Union, irrigation and water level. Over fishing of Issyk-Kul Dace stocks by the Soviet fleet based at Issyk-Kul Lake was presented in [11]. The disintegration of the Soviet Union had profound economic and social effects, especially in the fisheries sector of the newly independent transition economies [28]. Nowhere were these production shortfalls bigger than in Kyrgyzstan where Lake Issyk-Kul fish landings were in 2003 less than 7 per cent of the catch level recorded in 1989. The major consequence for the fisheries sector was the spectra of uncertainty which included the uncertainty of, how the sector was to be managed, how access to water bodies was to be regulated, how to maintain the backward and forwards supply chains which underpinned pond aquaculture, and livelihoods – as the Soviet guarantee of job security was rescinded. Many experts and professional fishers left the sector to find employment in other sectors in Kyrgyzstan or abroad. Intensive irrigation led to reduced water levels in the lake and more importantly heavy water abstraction caused drying of many incoming streams that the endemic fish species previously used for feeding and/or spawning [34,35]. It has been shown that biological productivity of Lake Issyk-Kul decreased from 1973 to 1981 when the water level was declining at a rate of 7-10 cm per year [36].

5.2. Hatchery failure

Reproduction of many alien and endemic fish species was severely constrained by the limited number of suitable spawning rivers. As a consequence, the state established hatcheries on the Ton (1964) and Karakol (1969) rivers – with the brief to capture spawning fish, extract the eggs, raise the fry-fingerlings produced, and thence restock the lake. According to [7], the minimum Sevan Trout return in landings is given as 2% of releases; that means that at least 750,000 fry, each of 1 g weight, must be produced and released annually. Assuming an egg mortality of 50%, hatcheries should produce 1.5 million eggs per year. Ton hatchery produced 9 million fry annually in 1989-91. After the breakdown of the former Soviet Union the state hatchery production went down sharply. Over the period 2004-8 Ton Hatchery continued to restock the lake with Sevan Trout at much reduced rate, 446,000 fingerlings annually. Nowadays (2010) Ton Hatchery is able to release some 900,000 fry with 40% egg survival. No endemic fish fry

have been produced despite of the capacity, but Rainbow Trout fingerlings have been produced on a contractual basis for the cage farmers.

Estimated IMPACT	**Strong negative** impact	**Some negative** impacts	**Not visible** impact	**Some positive** impacts
Introduction of alien fish species	Yes			
Introduction of alien food species				Yes
Over fishing	Yes			
Illegal fishing			Yes	
Disintegration of the Soviet Union 1991		Yes		
Cage culture	Yes			
Moratorium	Yes			
Hatchery failure	Yes			
Tourism		Yes		
Water level		Yes		
Irrigation	Yes			
Water pollution		Yes		
Climate change		Yes		
Radioactive leakage			Yes	
Military activities			Yes	
Mining activities	Yes			

Table 4. Impact evaluation of different natural and anthropogenic factors on fish stocks and biodiversity

During 1966-1973 over 12 million Whitefish fry were released annually from the state-owned Karakol Hatchery, but 1977-1988 fingerling production went down to 1 million per year. After privatization Karakol Hatchery has been able to produce below 2.5 million Whitefish fry annually, explaining why the collapsed Whitefish stocks are not recovering, as obviously very little or no natural reproduction takes place in the lake.

These drastic declines in restocking have undoubtedly been one contributor to the decrease in recorded fish landings at Issyk-Kul Lake.

5.3. Cage farming of fish

The cage farming of Rainbow Trout started in 1988 by Alfa Laval Avose, but was not economically viable due to the high cost of feed. Obviously large number of fingerlings escaped into the lake, when the storm was turning the experimental cages around. In 1989-

90 the company was able to produce 20 tonnes of Rainbow Trout. After the collapse of the USSR there was no development of this activity before 2006 when Ecos International commenced cage farming activities at Issyk-Kul Lake. Since that time exponential growth in trout culture has taken place.

Nowadays the existing eight cage farms and their 26 cages (as in April, 2009) are producing well over 300 tonnes of Rainbow Trout per year [37]. This production is causing pollution in the form of medicaments used for the treatment and prevention of diseases and pathogenic bacteria and parasites. By authorizing lake-based cage culture of Rainbow Trout, the authorities are allowing inevitable eutrophication. Extra nitrogen and phosphorus from unused feed will add to the primary production of algae and lower oxygen level. The second problem is the excess feed which sinks to the bottom of the lake through the net cages. At the bottom, sinking feed and faeces and urine of fish will cause the formation of hydrogen sulfide gases harming the other users and fauna of the lake. The worst, however, is the unwanted new continuous introduction of that predatory fish to the lake, because especially large specimen can and will escape the cages. After that they move around the lake and eat a lot of endemic fish species. According to fishermen (personal interviews in 2009) Rainbow Trout is the main predator in the lake, even more predacious than Pike-perch, because it comes to prey in shallow waters near the shoreline while Pike-perch often remains in the deeper waters (Figure 5).

5.4. Moratorium and illegal fishing

In order to protect the decreased fish stocks in the lake, the President of the Kyrgyz Republic declared a Moratorium for Artisanal and Commercial Fish catching for a period of 10 years (2003-2013). The need for total ban was stated to be illegal and over-fishing which was seen as the only reason to loss of fish resources and endemic species. But the moratorium can become an effective measure of restoration of fish resources in the lake only if mechanism of implementation and realization (fish inspections etc.) is developed as well. Otherwise the moratorium will not work. Despite of the total ban at least 500 people continue their activity as illegal fishermen. On average they are catching 5 to 20 kg per night, but every fourth night is stormy making artisanal fishing with small boats impossible. If fishing 100 nights per year, they are catching between 250 and 1000 tonnes per year. Should this fairly conservative estimation be true, the lake is fished at level of 0.4 - 1.6 kg/ha. So this hardly can be seen as over fishing in a lake where theoretical production capacity is estimated at 4.5 kg/ha [34]. This of course by assuming that the fish stocks have in the last ten years recovered from 2003 level after the total ban of commercial fishing.

5.5. Management and conservation possibilities

It is far too easy to blame over-fishing that some species became nearly extinct and that fewer fish are caught. More important problem is the absence of any fisheries management and lack of controlled protection of fish resources. Removal of the fishing ban is necessary, since it cannot be controlled and monitored. Exploring co-management arrangements is a



Figure 5. This kind of 7 kg Rainbow Trout eats a lot of small indigenous fish species. Photo: Azat Alamanov

better option than command and control as the resources are not available for such policy measure [15]. If more than 500 people are continuing fishing despite of the moratorium, the policy needs to be evaluated for better stewardship outcomes. Actually it is far more important to continue to fish large predatory fish, if having any concern of the survival of native non-predatory species.

However, commercial fishing needs to be reconsidered after the moratorium, in 2014, as recreational and food fishery may be far more sustainable. Due to the growing importance of Lake Issyk-Kul for recreation, fishery management might go in the direction of producing valuable sport and recreational fish to satisfy the demand of the tourists and visitors. Such recreational fishing will basically target large predatory species- Rainbow and Sevan Trout and Pike-perch, which are the favourite species for sport fishing. Recreational fishing of large fish will promote Issyk-Kul Lake as more attractive for tourists. It will also help fishery managers to shift proportions of predator and prey fish species and diminish the negative effect of alien predators towards vulnerable stocks of endemic fish species.

Rare indigenous species stocks will not improve without artificial propagation in local hatcheries. This production of fry has started through UNDP/GEF Project, but stocking the lake with small indigenous is not viable before considerable harvesting of large predators. The number of Sevan Trout is easy to regulate, as it mostly depends on the stocking rate of fingerlings into the lake and these are reproduced artificially in the hatcheries. Rainbow Trout and Pike-perch are more difficult to remove if they are able to multiply in the lake (Figure 6.). Improved stocks of small endemics could take care of these predators by eating their eggs and small fry, like small fish did in Lake Victoria by preying on eggs and fry of the Nile Perch [32].

5.6. Water pollution

Widespread mining operations are causing disruption of soils, terrain and water tables but more serious water pollution comes from illegal dumping or storing of toxic chemicals currently in use at Kumtor gold mine, in Tian Shan Mountains. It is the largest gold mine, as well as a major government revenue source, which routinely ignores national environmental legislation. Kumtor mine reportedly uses up to 10 tonnes of cyanide per day in its mining operations, and number of chemical constituents is released into the environment [38]. By sure this is affecting fish populations downstream and the health of local people using the contaminated water or fish (Table 5).

One of the worst regional environmental disasters in recent history occurred on 20 May 1998, when a truck hauling toxic chemical crashed just upstream from the mouth of the Barkuum River, which empties into Lake Issyk-Kul. As a result, 1762 kg of sodium cyanide, a chemical used in the processing of gold ore at Kumtor, were dumped into basin waters [6].

Lack of both adequate infrastructure and financial means to support public utilities (let alone any resort or tourism industry) has made it impossible to improve wastewater treatment plants. This in turn leads to further pollution and unwise use of lake waters. The gradual increase in settlements and industries around the lake has led to an increase in

pollution. Although most enterprises have wastewater treatment facilities they are not efficient and some effluents still reach the lake.



Figure 6. Artificial nests are used to remove the eggs of Pike-perch from the lake to reduce the numbers of that alien predatory fish. Photo: Azat Alamanov

Agriculture, through the use of fertilizers and pesticides, also contributes to the lake pollution, but level of fertilizer application on crop fields is known to be moderate. However, the Issyk-Kul area produces 12% of total national cereal crops and over 40% of potato crops. Of the total area of orchards nationwide, 20% are in Issyk-Kul. Numbers of domestic animals in the catchment area is very high: Cattle 163,500; sheep 1,944,400; swine 32,700; poultry 623,400 and horses 48,500 [39]. Dairy product processing covers 50% of the national dairy product supply. Animal breeding is growing, with average annual sheep and cattle surplus at 5-6%. Grazing land is overloaded by 1.5 times its capacity (Figure 7). Grazing practices have changed so that all livestock owned by small proprietors are now grazing near the lake as the farmers have no transport nor money to drive their animals upland to outlaying pastures. That could cause social conflict (grazing on beaches and resort areas) and eutrophication of the lake but luckily people are commonly collecting the manure for fire or fertilizing. While the large volume of 1738 km^3 of water in the lake may have at present considerable diluting capability and with the good water mixing is also able to quickly oxygenate organic matter inputs to the lake, sheltered shallows are subject to

eutrophication. As the shallows are also important spawning and feeding areas for a number of fish, such eutrophication may affect especially those cold-water fish species which require pristine waters, like Whitefish.



Figure 7. These camels are the only memory of the Silk Road at the Issyk-Kul Lake coast of which is heavily overgrazed by the domestic animals. Photo: Azat Alamanov

Eutrophication caused by birds is not often considered as a problem, but in the Issyk-Kul Lake the amount of migratory birds is such that it will affect the lake. Anywhere from 44,000 to 68,500 birds belonging to 30 to 35 species winter on the lake, and even more birds use it as stopover and feeding place during spring and autumn migration [40].

5.7. Climate change implications

Within the Issyk-Kul basin there are 834 glaciers of various sizes ranging from less than 0.1 to 11 km^2. For example, a typical Issyk-Kul glacier Karabatkak has shown in long-term study between 1957 and 1997 that ice loss exceeded snow mass gain by 18 m.

This thinning of ice is due to climate change, summers have been 0.6 degrees Celsius warmer, although the annual average temperature has risen only 0.2 degrees Celsius. Based on this it was calculated that before 2005 overall glaciation area near the lake will go down 32% on the northern slopes and even 77% on south-facing slopes [41].

The continuing retreat of glaciers in the Issyl-Kul catchment, the melt water from which is one of the major contributors to the lake, seems to be going in parallel with the declining lake water level [42]. Without glacial runoff overall drop in lake's water level would have been much greater.

The Kyrgyz Republic is within a high seismic activity area, and Issyk-Kul is a tectonic lake, and the lake bottom is believed to have numerous warm water springs. These explain partly why the lake never freezes over, except in the shallow Rybachinsky and Tyup bays. The water stays warmer than the air for seven months per year [39].

Hot springs at the lake and on the bottom change water quality and may facilitate winter spawning of some introduced species like Pike-perch. During the test fishing in early April 2009 we found after opening a 40 cm Pike-perch that it had preyed another (12 cm), and even that small prey had eaten a few juvenile Pike-perch, not more than 5 cm long. It was estimated that these 3rd level victims of cannibalism must have been born early February. This kind of winter spawning is not known before but could obviously take place due to the hot springs.

5.8. Other human activities

There are recent reports on the radioactive waste contamination in Central Asia [43] showing that the situation is critical especially in Kyrgyzstan, with 36 tailing sites and 25 uranium dumps in the country. Kadzhi-Say, the country's largest tailing site (containing 150,000 m^3 of radioactive waste), is located barely 1.5 km from Lake Issyk-Kul. Yet although some information is available on the impact of radioactivity on humans, it is not well studied or understood what direct impact the current radioactivity levels have on the aquatic biodiversity in Kyrgyzstan. The monitoring of water bodies for radioactivity is not done consistently and to date, no assessment has been made of the uranium contamination of fish populations of indigenous species and its consequences for fish stocks in Kyrgyzstan. It is not clear, if and how much radioactive waste has already gone into the lake or still goes from incorrectly closed tailing sites and uranium dumps.

During the Soviet period, the USSR Navy operated an extensive facility at the lake's eastern end, where submarine technology was evaluated. Also Navy tested torpedoes built in Tashkent. Not known if torpedoes exploded in these experiments. If so this must have killed a lot of fish. In 2008 Kyrgyz newspapers reported that Russian Navy is planning to establish a new naval testing facility around the Karabulan peninsula on the lake. This may affect the fish stocks in the future depending on the tests undertaken.

During the Soviet era, the lake became a popular vacation resort, with numerous sanatoria, boarding houses and vacation homes along its northern shore. These fell on hard times after the break-up of the USSR, but from 2005 onwards hotel complexes are being refurbished and simple private bed- and –breakfast pensions are being established for a new generation of health and leisure visitors (Table 5).

Tourism has become one of the most dynamically developing sectors of economy of the Kyrgyz Republic. The number of arrivals of foreign tourists is expected to exceed 2 million persons per year. International tourists are primarily from Kazakhstan, Russia, and

Uzbekistan. If half of these tourists will visit the lake, there is need to accommodate an additional 1 million persons per year at the lake in hotels using natural beaches for recreation. Nowadays the lake has 343 tourist enterprises, including cafes and restaurants.

Years	Population in '000	Visitors in hotels	Visitors at homes	Total in '000
2006	430	198	296	924
2007	433	199	245	877
2008	435	194	349	978
2009	438	169	318	925
2010	441	181	227	849
2011	445	185	231	861

Table 5. Permanent population and annual visitors in the Lake Issyk-Kul area [44].

In addition, large hospitals have been built to use medicinal mud and hot springs along the coasts for medicinal purposes. Regulations exist for water system supply and to use fully purified sewerage systems. Recycled waste water could be used for irrigation. Unfortunately, some entrepreneurs have forgotten these regulations, and continue to pollute the lake as no corruption free control exists.

Asian Development Bank study [45] has concluded that available water and sanitation and waste disposal infrastructure in the Issyk-Kul area is decrepit, dysfunctional, poorly managed and negatively impacts the surrounding environment. The planned tourist influx equivalent to four times the resident population applies excessive pressure on the existing infrastructure, which results in the pollution of the lake. The proposed Issyk-Kul Sustainable Development Project initiated by the Asian Development bank (ADB) would address the environmental and institutional issues around the Lake Issyk-Kul. The Japanese International Cooperation Agency will also develop the sewerage system and sewage treatment plant in Cholpon-Ata through parallel financing with the ADB.

6. Concluding remarks

Issyk-Kul Lake is the second largest high-altitude lake in the world providing recreational and small-scale fishing activities as well as cage culture of Rainbow Trout in the Kyrgyz Republic. The original fish fauna comprised twelve indigenous species and two subspecies particular for this lake. At least 19 species have been introduced to the lake by humans, either on purpose or accidentally. The populations of several indigenous fish are seriously threatened, because many of the introduced fish species are potential predators. Issyk-Kul Marinka, Naked Osman and Sazan Carp are those commercial and indigenous species which are most seriously endangered. In 1986 a total ban was declared for catching Naked Osman, but it did not lead to positive results, indicating that anthropogenic activities were not the only reasons for the suffering of the endemic fish species.

Fishers and most of the previous papers are convinced that the predatory fish species have been the most destructive to biodiversity. Addressing the introductions, the basic rule

should be that new human introduced alien species are not allowed to enter into the lake. At least any further fish introductions into the lake should be carefully evaluated to prevent unwanted changes in fish stocks. Issyk-Kul, as an oligotrophic lake of low productivity, has a low carrying capacity for fish; hence it will never become a water body which would sustain high levels of fish stocks.

Dissolution of the Soviet Union explains to some extent the collapse of the fisheries sector (including the hatchery operations) in Kyrgyzstan, but maybe not the loss of biodiversity. Rapid growth in human activities with the development of tourism industry; irrigation; water eutrophication and pollution, and climate change impacts seem to be important root causes for loss of fish stocks and biodiversity degradation.

Uptake of water for irrigation is one of the factors seen to be responsible for the present changes in the water level as water from most of the rivers has been completely diverted for irrigation before reaching the lake. Irrigation hinders also the river reproduction of many species as it prevents spawning fish from entering the rivers or fry to return to the lake. During 1960-1979 when fish catches started to decrease the total decline of the water level was 140 cm, at an average rate of seven cm annually. That loss of water level has been one important factor affecting the fish stocks and fisheries.

There are recent reports on the radioactive waste contamination in Kyrgyzstan, where the country's largest uranium tailing site is located barely 1.5 km from Lake Issyk-Kul. It is not clear, if and how much radioactive waste has already gone into the lake or still goes in from incorrectly closed tailing sites and uranium dumps. Maybe even more serious water pollution comes from illegal dumping or storing of toxic chemicals currently in use at a gold mine in Tian Shan Mountains. It is the largest gold mine, as well as a major government revenue source, which routinely ignores national environmental legislation. This mine uses daily up to 10 tonnes of cyanide in its operations, and many of toxic chemicals are released into the environment. This is surely affecting fish populations downstream and the health of local people using the contaminated water or fish for drink and food.

Existing water and sanitation and waste disposal infrastructure in the Issyk-Kul area is decrepit, dysfunctional, poorly managed and has negative impacts on the environment. The planned tourist influx equivalent to four times the resident population will apply excessive pressure on the existing infrastructure, which will result in further pollution of the lake.

Important problem is the total absence of any fisheries management and lack of controlled protection of fish stocks and diversity. Fishing ban is not helpful as it cannot be controlled and monitored. Exploring co-management arrangements is a better option than command and control as the resources are not available for such policy measure. Rare and endangered indigenous fish species will not increase without artificial propagation in local hatcheries. Stocking the lake with small indigenous species is not viable, if not first harvesting the large predators. Pike-perch would just eat small indigenous species and grow bigger and spawn more.

Over-fishing of introduced species, like Rainbow Trout and Pike-perch, could be a good thing. As popular food fish and recreational catch, they could be severely over fished. This

could lead to population reduction, and several populations of endemic fish species should soon show signs of increasing numbers. So the authors should allow the local fishing communities capture large introduced fish species as much as they can rather than restricting them through moratorium.

Any new development initiatives must be consultative and participatory in order to be more consistent with local habits and cultural values. Inherited customs provide an important element for the development of locally based resource management system. Consequently, allocation and sustainable management of natural resources is one of the key issues for the local population, whose daily cash economy is directly dependent on availability of fish resources.

Before being able to define the best management ways, one needs further research in taxonomy and fish biology. The knowledge of fish stock parameters is essential for the determination of appropriate fisheries management and definition of sustainable fish yield. Impact of mining toxins and radioactive waste is important to study and to know for control measures. Water pollution is a continuous risk for this important lake, and has to be halted in the future. The Kyrgyz public must be engaged in the future through environmental education in conservation and preservation of natural and cultural riches of the Issyk-Kul area.

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