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Impact of overgrazing and climate change on the lake ecosystem in arid region

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Abstract
Mongolia's geographical location, extreme climate, fragile ecosystems, agricultural dependence on climate requires adaptation to global climate change and smart usage of natural resources. The water level of most lakes in Mongolia had been steadily increasing from mid-1960s to 1995 and declining from 1996. The purpose of this study is to determine current condition by each ecosystem compartment in and around the Lake Duruutsagaan and to define cause of the lake shrinking and deterioration of ecosystem. The Lake Duruutsagaan ecosystem study was carried out in the following natural elements: climate, hydrology, hydrobiology, forest, soil, pasture, plant species composition, and animals. The lake surface area was slightly decreased by 24.21% from 10.02 km^2 in 2003 to 7.59 km^2 in 2017. The lake water is highly mineralized, probably due to increases of evaporation of water. Also elevated concentrations of some chemical elements are detected in the lake water, including Phosphorus (22.6 mg L^{-1}) and Arsenic (198 mg L^{-1}). The high concentration of these two elements shown different kind of pollution existed in the lake. Probably, arsenic content in lake water is related to the geological composition of surrounding area, but elevated concentration of P can be attributed to the nutrient pollution due to soil erosion in surrounding area of lake. Species diversity in this lake is limited and only a few species of crustaceans that can tolerate under high salinity and polluted condition are present. All of soil samples have a low content of clay particles (between 2.6-8.5%). According to the soil samples data, pasture land in study area is moderately 80.95%, strongly 7.04% deteriorated due to direct and indirect effects of overgrazing. Especially, natural regeneration is not observed in the forest area. According to the study results, current condition of Lake Duruutsagaan and its surrounding area is indicating the need for some protection and restoration management.

Keywords
Lake area, climate change, soil degradation, overgrazing in rangeland, forest

Introduction

Drinking water sources are the most important sources of livelihood in Mongolia under harsh and arid continental climate. The fact that 84% of the total water resources are in the lakes shows that the social, economic and environmental situation in Mongolia is inextricably linked to the lakes [1]. As a result of geological evolution, many lakes have formed on the plateau of Central Asia. Those water sources have been supporting the nomadic way of life, wildlife and proving a habitat for migratory birds. However, many of the lakes are shrinking or completely dried up due to misuse of lake resources, aquatic pollution and climate change. The shrinkage and drying up of lakes have exacerbated the regional ecosystem degradation and directly threatened the livelihood of nomads [2].

The first census of lakes and ponds in Mongolia was conducted in 1940 [3]. According to the census, 4296 lakes and ponds were counted, and their total area was 15514.7 km^2 [1]. Compared to the 2015 Landsat data, the total number of lakes and ponds decreased by 832, while the total area decreased by 1202.1 km^2 or 7.8% [1],[3].

Over the past 20 years, the lake surface area has decreased by 220.2 km^2 in small lakes (1-10 km^2) and by 120.5 km^2 in medium (10-50 km^2) sized lakes, but increased by 8.4 km^2 in large lakes (>50 km^2) [4]. This suggests that small and medium -sized lakes are relatively sensitive to human activities and climate change. Therefore, previously unexplored small and medium-sized natural lakes should be used for social and economic needs on a scientific basis, with a proper relationship between human needs and the functioning of the lake ecosystem. In Mongolia, the water balance, regime, lake water chemistry and biological systems of large lakes are being studied in more detail, but small and medium-sized lakes have not yet been studied.

Lake Duruutsagaan is one of the shrinking lakes in the northern Mongolia. The cause of drying and degradation of the lake ecosystem is not clear even though it can be related to global warming, and on the other hand, environmental degradation, and exploitation. From previous studies, only brief description of the lake is available [5] and study materials of this lake ecosystem and surrounding areas are scarce. Therefore, it is essential to study each compartment in lake ecosystem to define causes of land degradation and lake shrinking.

The purpose of this study was to determine current condition by each ecosystem compartment in and around the Lake Duruutsagaan and define cause of the lake water degradation and shrinking. The Lake Duruutsagaan ecosystem study was carried out in the following natural elements: climate, hydrology, hydrobiology, forest, soil, and grassland plant species composition.

Material and methods

The study area

Lake Duruutsagaan is located in north central Mongolia (N 49°02'08", E101°12'15"), about 650 kilometres from the Mongolian capital city Ulaanbaatar (Fig. 1). The lake is formed between the continuous medium high mountains in Khangai mountain range, which is an old mountain range in central Mongolia. Elevation of the lake is 1712 m above the sea level. An ecosystem study of Lake Duruutsagaan was carried out in the following natural elements: climate, hydrology, hydrobiology, forest, soil, and grassland plant species.

<u>Climate:</u> Meteorological dataset of meteorological monitoring station in Rashaant soum, Khuvsgul province (Fig. 1) were used to determine changes of local climate conditions during 1963-1984 and 2004-2016.

<u>Hydrology:</u> Changes of lake surface area was determined from 2003 to 2017 (Fig. 3). Satellite data was used to determine changes of lake surface area.

<u>Water quality:</u> Physicochemical parameters (including water temperature, pH, and EC) were measured from the water samples in the field using YSI Multiparameter (Model 556 MPS). Dissolved Phosphorus was determined by a modified molybdenum blue method [6]. Chlorophyll A, dry weight, ash free dry weight (AFDW) was measured in the biofilm, which was collected from littoral zone of lake bottom. On the water samples, some chemical elements were measured by using ICP 80T at SGS IMME Mongolia laboratory.

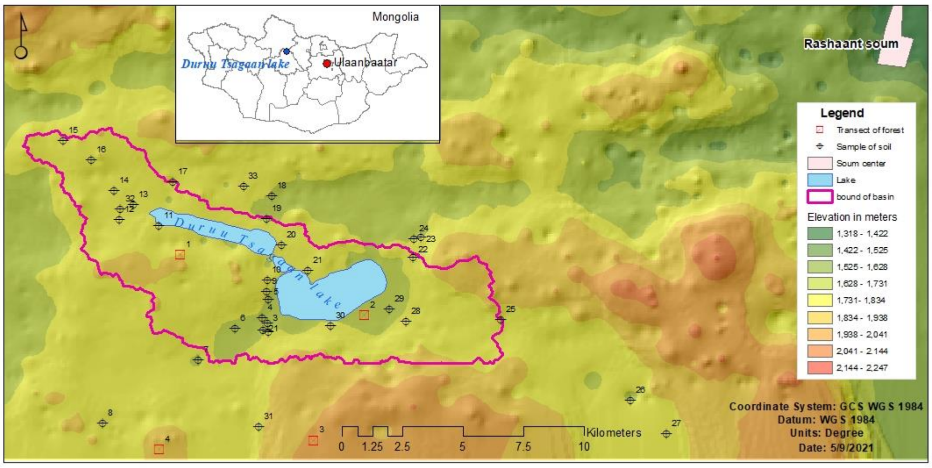


Figure 1. Digital elevation map of study area with soil and plant sampling points, transects of forest survey and location of meteorological station, which is located at Rashaant soum, Khuvsgul province.

Hydrobiology: Zooplankton sampling was carried out by dragging a conical plankton trawl net with mesh size of 72 μm from bottom to surface of the lake. Three sample replicates were collected at each sampling station and all filtered samples were preserved with 4% formalin. Prior to zooplankton sampling, physicochemical parameters (dissolved oxygen, temperature, pH) were measured. Sorting, identification, and counting of organisms was carried out under a microscope. Zooplankton identification was analysed at the lowest possible taxonomic level according to the standard taxonomic references [7].

Forest: The nearest forest patches in the lake drainage area were selected and 6 sampling plots (each plot size is 10 m x 10 m) were chosen along randomly selected linear transect from lower part of the forest to upper border (Fig. 1). All larch trees (*Larix sibirica*) with a stem diameter of at least 3 cm were included in wood-core sampling for tree-ring analysis. If visibly older trees were available outside the plots, they were additionally sampled as reference samples to establish long term tree-ring chronologies, but not included in plot-related calculations. Wood core samples were collected at breast height (1.3 m above ground) using an increment borer with 5 mm inner diameter. Regeneration study of seedling and sapling counting were conducted in 42 small squares with 1x1 m size (each square plot).

After bringing samples to laboratory, annual tree-ring width were measured with a precision of 10 μm on a movable object table (Lintab 6, Rinntech, Heidelberg, Germany), where the movements are electronically transmitted to a computer system equipped with TSAP (Time Series Analysis and Presentation)-Win software (Rinntech). Three age classes (old >110, medium aged 70-110 and young 20–70-year-old) were distinguished in the analyses.

Soil: Soil samples in various landscape features with different soil horizons were collected from 33 sampling site. Soil colour, thickness, structure, density, moisture, mottles, gravels, and plant root distribution were identified in each soil horizons of all soil profiles during field survey. Sampled soils from each soil horizons were stored in polyethylene bag and transported to soil and agro-chemistry laboratory in Mongolian University of Life Science.

At the laboratory, soil samples were air-dried and sieved through a 2 mm screen for experimental analysis. The humus, pH, available phosphorus, potassium, nitrogen, and soil texture were measured on the soil samples.

Plants and grassland: Plant cover was evaluated in the 8 km buffer zone from lake shore at each distinguished vegetation community. Plant cover analysis is based on photographic monitoring, which is modified from [8] and 33 plots were taken along each transect line. Plant species was identified based on key to the vascular plants of Mongolia [9]. All the study area was divided into one of four different grazing impact categories, namely healthy grassland and slightly, medium, strongly degraded grassland [10].

Results and Discussion

Impact of changes in climate condition on shrinkage of lake

Figure 2A shows the average monthly air temperature of the study area including two separate datasets (1963 – 1984 and 2004 – 2016). According to data, study area cooled down in winter and spring months (December, January, May, and June) by 1.3-2.9 ^{0}C and slightly warmed in April and July-October. The average annual temperature for 1963-1984 was 0.5 ^{0}C, but it was decreased by 0.1 ^{0}C in 2004-2016. Those results indicate that there was not much warming observed in this region, although it is assumed that in northern mountainous region of Mongolia climate conditions have been changing and warming trend has been observed [11].

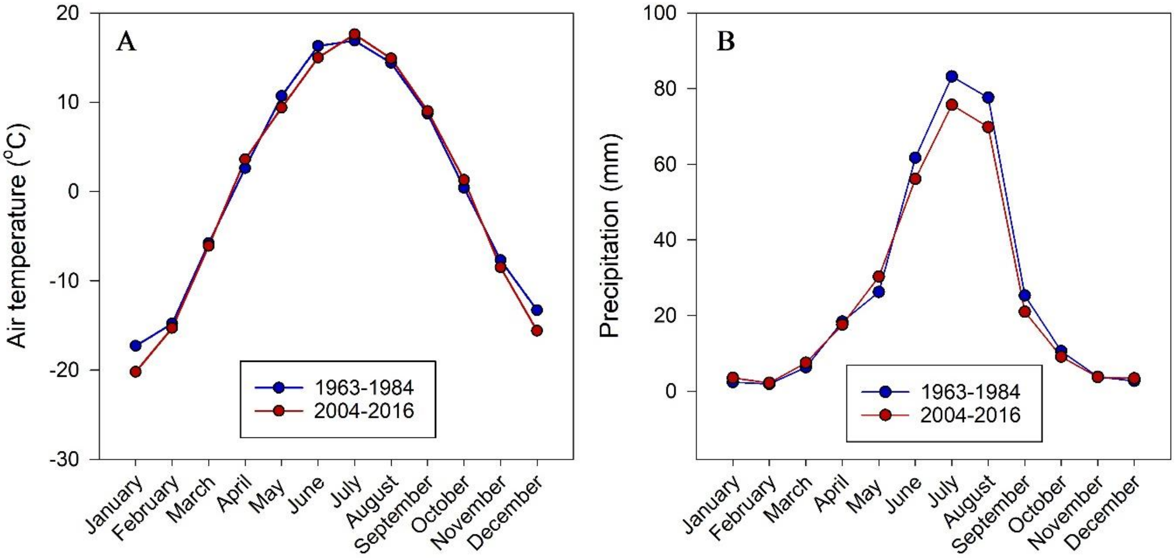


Figure 2. Comparison of air temperature and precipitation between two different period, visually 1963-1984 and 2004-2016. (A) shows average monthly air temperature for two periods. (B) shows average total precipitations in each month for two periods.

Recent years' precipitation has decreased by 20 mm compared to the average monthly precipitation for 1963-1984. In the warm season, it decreased by 23.3 mm while wintertime precipitation increased by 3.3 mm, showing that the seasonal pattern of precipitation has slightly changed (Fig. 2B).

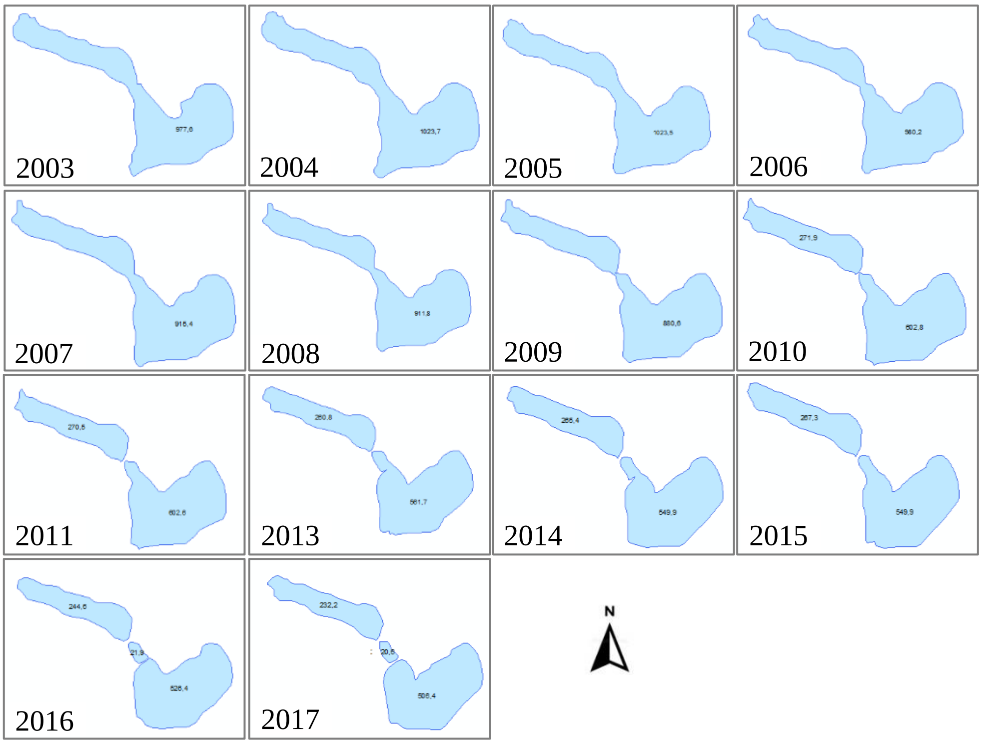


Figure 3. Changes of Lake Duruutsagaan surface area from 2003 to 2017

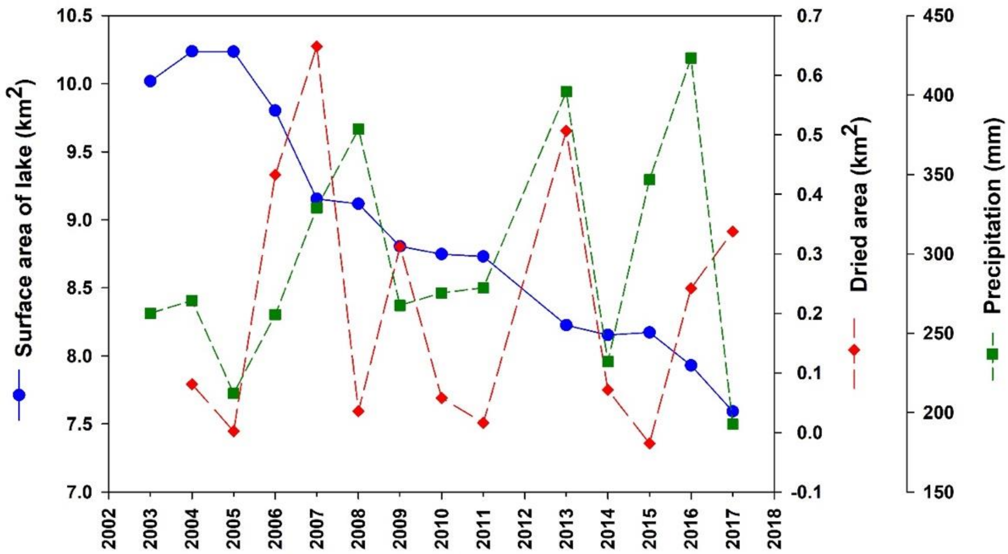


Figure 4. Changes of lake area and increases of dry land between 2003-2017, along with total precipitation in each year is shown. Blue circles with blue line show changes of lake area, red rhombus with red dashed line indicates increases of dry land due to shrinkage of lake and green square with green dashed line shows total annual precipitation in each year.

The lake surface area slightly decreased from 10.02 km^2 in 2003 to 7.59 km^2 in 2017. For 14 years, the lake surface area decreased by 24.21% (Fig. 3). In general, the shrinking or drying of lake should be low when the precipitation is high. However, opposite trend observed in the most years (Fig. 4). Area of Lake Duruutsagaan was greatly decreased when precipitation was high, but some years lake area was slightly decreased when precipitation was low. Probably, precipitation is not main driver of shrinkage of lake, which was confirmed with lower correlation (R^2=0.036) between total annual precipitation and annual increases of dry land.

Water quality and aquatic life of Lake Duruutsagaan

Hydrochemical parameters indicate that not only water level is decreasing but also there is some worse results related to the lake water quality. For example, Arsenic concentration is 20 times higher than both world health organization guidelines for drinking water quality and Mongolian national standards for surface water quality [12]. The concentration of phosphorus in lake water is too high (22.6 mg L^{-1}) (Table 1). The major cations content (Ca 98 mg L^{-1}, Mg 45 mg L^{-1}, Na 3360 мg L^{-1} and K 45.3 mg L^{-1}) in the lake water is high. According to the classification of lakes, this lake belongs highly mineralized, saline lakes.

Table 1.

Concentration of dissolved elements in Lake Duruutsagaan water

№	Measured elements	Unit	Lake water	Spring water
1	Ag	µg L^{-1}	-	-
2	Al	µg L^{-1}	-	-
3	As	µg L^{-1}	198	0.71
4	Ba	µg L^{-1}	23	-
5	Cd	µg L^{-1}	0.02	-
6	Co	µg L^{-1}	0.39	0.07
7	Cr	µg L^{-1}	-	-
8	Cu	µg L^{-1}	-	-
9	Fe	µg L^{-1}	-	-
10	Hg	µg L^{-1}	2.8	-
11	Mn	µg L^{-1}	-	-
12	Mo	µg L^{-1}	21.7	0.9
13	Ni	µg L^{-1}	0.9	0.6
14	P	µg L^{-1}	22553	-
15	Pb	µg L^{-1}	-	-
16	Sc	µg L^{-1}	8	2
17	Sr	µg L^{-1}	417	124
18	U	µg L^{-1}	29	4.04
19	W	µg L^{-1}	72.7	0.34
20	Zn	µg L^{-1}	-	<5
21	Zr	µg L^{-1}	32.5	0.30

Nine species of planktons were recorded in the Duruutsagaan Lake, consisting of 5 species of rotifers *(Conochilus unicornis, Polyarthra vulgaris, Asplanchna, Keratella cochlearis, Trichocerca sp.)*, 2 species of Cladocerans (*Ceriodaphnia quadrangular, Simocephalus vetulus)*, and 2 species of copepods (*Metadiaptomus asiaticus, Cyclops lacustris*). Their density was different in the three parts of the lake. While East Lake has high abundance of rotifers and cladocerans, west lake had high abundance of copepods (Table 5).

Table 2.

Planktons that recorded in the Duruutsagaan Lake

Species name	East lake at 4-5 м depth		West lake at 1-5 м depth		Middle lake at 1м depth	
	ind/м^3	g/м^3	ind/м^3	g/м^3	ind/м^3	g/м^3
Rotatoria						
Conochilus unicornis Rousselet, 1892	45171	11.74	-	-	8809	2.29
Polyarthra vulgaris Carlin, 1943	697	0.18	-	-	-	-
Asplanchna girodi de Guerne, 1888	4885	1.12	14818	0.4	-	-
Keratella cochlearis (Gosse, 1851)	1386	0.027	1494	0.02	-	-
Trichocerca sp.,	1395	0.072	-	-	-	-
Total	53534	13.3	16312	0.42	8809	2.29
Cladocera						
Ceriodaphnia quadrangula (O.F. Müller, 1785)	-	-	10344	1.45	-	-
Simocephalus vetulus (O.F. Müller, 1776)	-	-	4039	0.3	-	-
Total	-	-	14383	1.75	-	-
Copepoda						
Metadiaptomus asiaticus	15015	5.7	11644	4.42	13214	5.02
Cyclops lacustris Sars, 1863	49002	1.81	7454	0.22	-	-
Total	64017	7.51	19098	4.64	13214	5.02

Results of the lake algae shows, *Enteromorpha spp.* distributed in our study lake, shows that this alga maybe brought by migrating birds, and it is needed to be noted that after heavy raining the lake water looked greenish-grey, this alga, indicating that the lake becoming highly polluted and protection measures are needed. In other hand, the decrease of precipitation and influents of streams to the lake can be one reason to increase the viability of this environment as mineralization increases [13].

The effect of terrestrial ecosystem on Lake Duruutsagaan

Forest: In the study area, larch forest /*Larix sibirica* L./ is distributed and according to Mongolian forest-vegetation region classification [14] it belongs to the Khangai mountain steppe-forest vegetation region, and North-Eastern Khangai forest-vegetation subregion, where light taiga forest dominates**.**

Age of young trees range from 20 to 70 years old, and often occur in small areas in the edge of the forests and in open zone of the forest. In our research site, young tree growth rates observed with a continuous decreasing trend (Fig. 5A), while general tendency for young tree growth should be regular or have higher growth rate (Fig. 5B). The results of the middle-aged (70-110) trees' annual growth show they had higher growth rate until 1925 (in the first 15 years) and then growth rate fluctuated, but starting 1945 growth rate has been persistently decreasing ($r = -0.74$, $p < 0.00001$). In the region, middle aged trees occupy 60-70 percent of the forests. Middle part of the main stems for older trees mostly were rotten, and therefore it was impossible to obtain information more than 150 year.

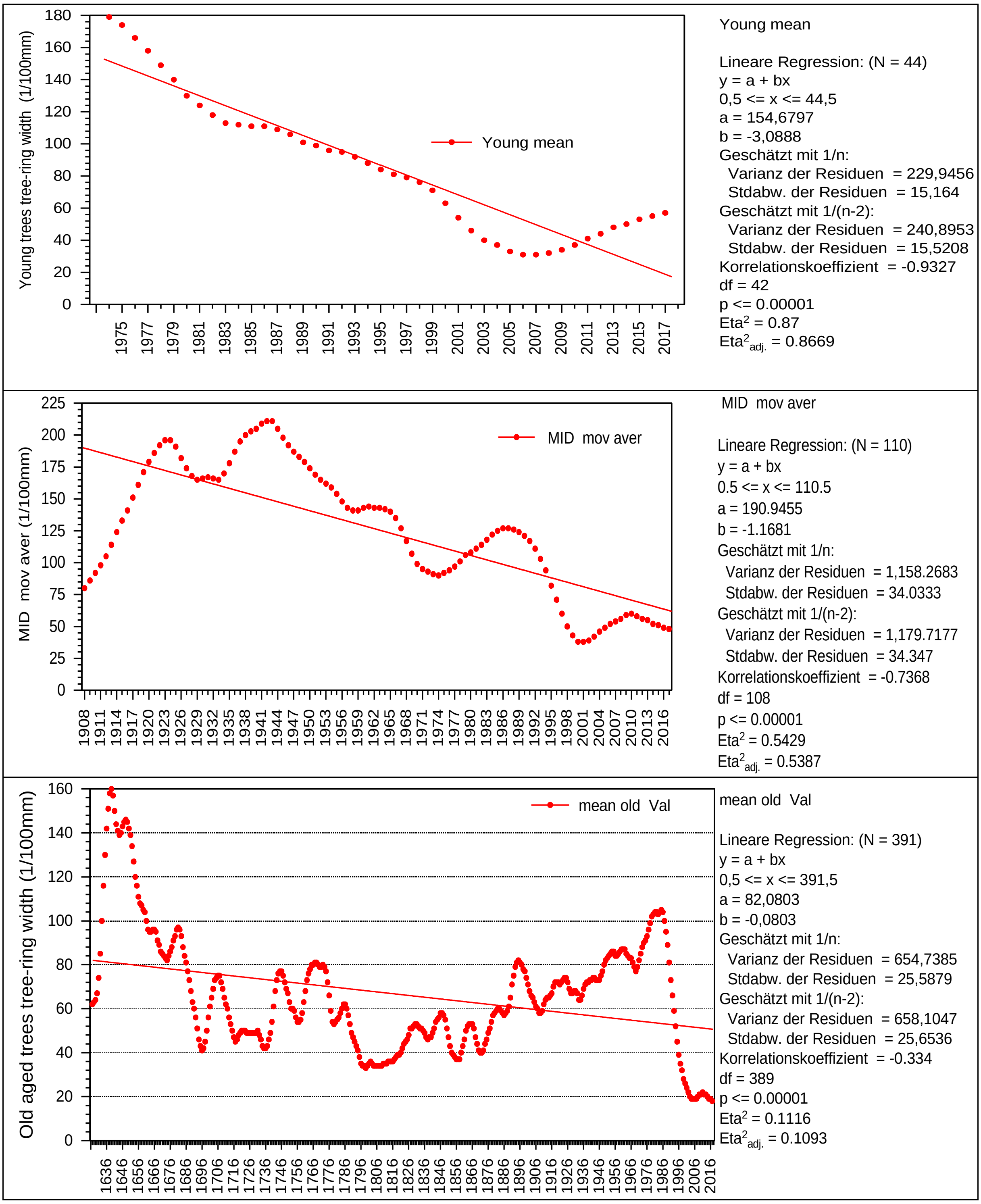
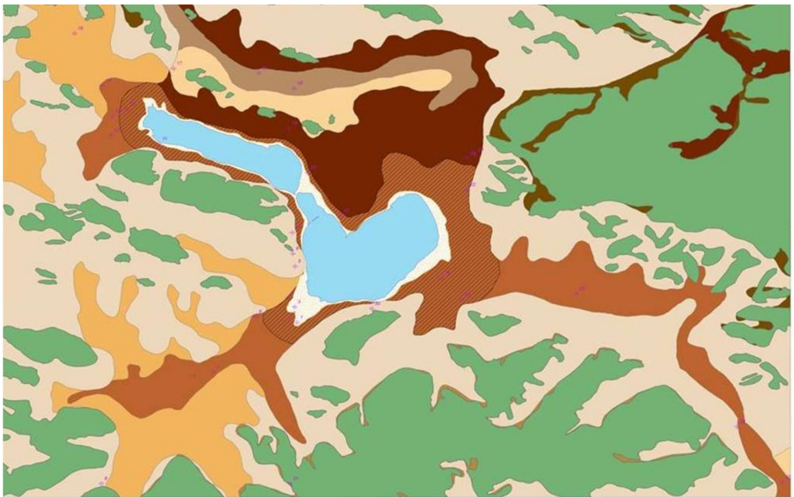


Figure 5. Annual growth of young (A), medium aged (B) and old (C) larch trees of the forest near Duruutsagaan lake

However, core samples from 4 trees of 2 different plots gave us the following growth tendency for 390 years (Fig. 5C). Generally, the peak of the growth rate observed when the trees were young, and this period occurred in 1640, and then gradually declined. In the 200-year period from 1680 to 1880 the growth rates were comparatively uniformly shaped with little increase and decrease fluctuations having around 20-year interval. Remarkably, since 1995-1996, the rate of growth has fallen sharply, with the least growth rate in the recent 10 years (Fig. 5C).

Soil: According to soil classification system of Mongolia [15], we illustrated 8 different type of soils, namely alluvial meadow stepped, mountain steppe, mountain meadow steppe, mountain meadow soil, mountain forest dark coloured, mountain dark coloured non-carbonated, and mountain dark coloured carbonated (Fig. 6). The amount of the humus ranged between 1.13 - 9.93% in mountain dark coloured soil and mountain brown soil, indicating this parameter is highly variable or can be said even small and big amount. Soil pH $_{(H2O)}$ were 6.4-7.5. Available elements P_2O_5, K_2O (mg/100g soil) were sufficient. Soil carbonate was presented in the thin layered mountain brown soil and there was powdered carbonate accumulation in the C horizon of mountain light brown soil. For the mechanical composition of the soil, percentage of the 0.25-1 mm particles was only 2.6-8.5 %, whereas the smallest particles (<0.001 mm), which is easy to be blown by wind was 20.4-29.0 %, and the gravels percentage was higher in the deeper part.

Plants and rangeland: Of the estimated 21825.07 hectares areas around Duruutsagaan lake, 36.7% is rocky land, 30.7% is rangeland with grasses, 13.3% is marsh land, 31.7% is forests, 1.1% is salt-marsh, and 3.8% is lake area. There are 20 different types of rangelands and 120 species of rangeland plants, 79 species of medicinal plants, and 5.7% of all plants are endemic species in Mongolia, and therefore these plants require plant protection program in this area (Fig. 6). The rangeland carrying capacity around the Duruutsagaan Lake has exceeded 2.5 times., 7,04% of the total area is strongly,80.95% is moderately degraded and the remaining 12.03% is forest area.



Land and soil type	Area (ha)	Percentage
The lake	824.2	3.8
Forested area		
Degraded area	1940.6	8.9
Alluvial meadow stepped soil	2178.68	10
Mountain steppe soil	9323.38	42.7
Mountain meadow steppe soil	1850.14	8.5
Mountain meadow	372.82	1.7
Mountain forest dark coloured	2618.81	12
Mountain dark coloured non-carbonated	1604.58	7.3
Mountain dark coloured carbonated	2421.09	11.09
Mountain brown soil	425.97	1.9

Figure 6. Soil types and their area and percentage of total area

According to these results, deterioration of surrounding areas in Lake Duruutsagaan is relating to the over population of livestock in this small valley. There are 57225.2 livestock as expressed to sheep unit in the lake valley. The rangeland carrying capacity at surrounding area of Lake Duruutsagaan is exceeded by 2.5 times due to grazing of livestock. Overgrazing was affecting the forest regeneration. During field survey, total 2100 sq.m area were examined but no saplings and seedlings counted in the study field, and only two seedling were present outside of the targeted plots. It is related to the shifting of grazing land from rangeland to forest area due to degradation of rangeland and reduction of plant growth. It can lead to the conclusion that there is a lack of regeneration in this forest due to increased effects of grazing

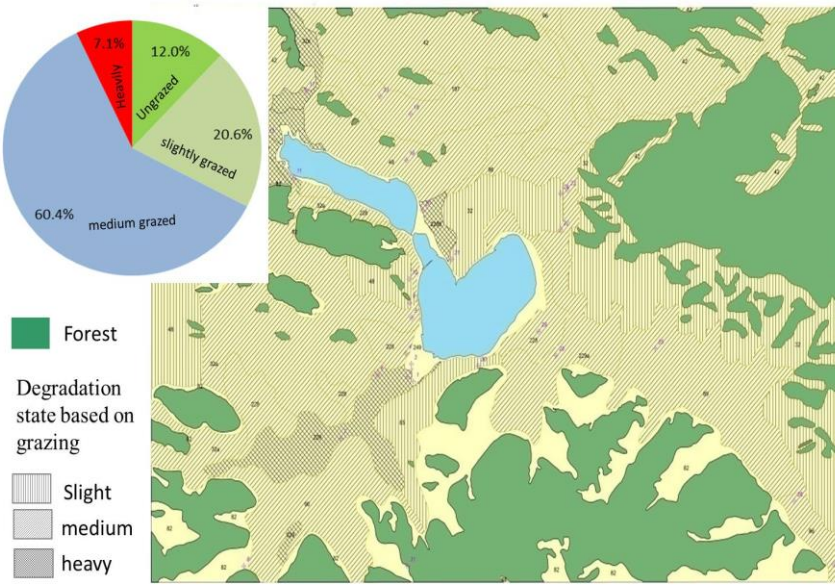


Figure 6. Pasture degradation map around the lake Duruutsagaan.
In the pie chart (east and upper) grazing intensity class and their percentage are given.

In addition, overgrazing was also affecting the stability of surface soil structure in rangeland and it was the main reason of soil texture to become sandy due to clay particles carried by wind and surface water runoff. The most of particles, which are carried by wind and surface runoff are possibly to sink into the lake and accumulate in the bottom of lake. This process creates favorable condition for increasing evaporation of surface water from lake, because particles are adsorbing more solar radiation compared to the clean water, and accumalation of particles on bottom of lake makes shallow water horizon, which is easy to heat up compared to deep water level. In addition, fine clay particles of surface soil are mainly secondary minerals, which is consisted of high content of nutrients and organic compounds. The influx of fine particles containing high amounts of nutrients were adversely affected to the water quality of Lake Duruutsagaan. One of the main limiting factor of lake primary production is a phosphorius, and it was dramatically high in lake water (P 22.6 mg L^{-1}) (Table 1). Probably, such high concentration of phosphorius is related to the surface soil erosion in this study area.

As mentioned before, shrinkage of Lake Duruutsagaan is not well related to climate change. According to the results, main water source of lake is groundwater. However, fine particles carried by wind and water from terrestrial area into lake fills lake bottom capillary pores, which is a ground water flow way. Under anoxic condition, accumulated secondary minerals of iron and aluminum form an impermeable layer on the bottom of lake, reducing groundwater infiltration.

Conclusion

The average annual air temperature in the region from 1940 to 2016 was not much increased, but precipitation decreased, and its seasonal distribution changed in our study region. Changes of lake surface area was not correlated to the annual precipitation and climate change in surrounding area. It was indicated, climate change is not main reason of the shrinkage of Lake Duruutsagaan.

The lake water is highly mineralized due to shrinkage of lake. Extremely high concentration of phosphorus was detected in lake water. It is indicated that the Lake Duruutsagaan is heavily polluted by nutrients. Also high concentration of Arsenic, which is a toxic, metalloid element is detected in lake water samples. Probably, such high concentration of arsenic is related to the natural background.

The rangeland carrying capacity has been exceeded 2.5 times in this small lake valley. Overgrazing has negative impact on the components of the ecosystem. Vegetation cover change is main reason for topsoil erosion and transport of fine particles with high content of nutrients from terrestrial area to aquatic environment by wind and surface runoff. Furthermore, this process is a major cause of lake water pollution by nutrients. Based on the phosphorius concentration, it is considered as a eutrophic lake.

Due to overgrazing of rangeland, livestock grazing in forest area is increased, because forest edge and forest area were slightly degraded, and vegetation grow well in forest. However, livestock grazing in forest has negative impact on forest regeneration. During field survey, total 2100 sq.m area were
examined but no saplings and seedlings counted in the study field, and only two seedlings were counted outside of the targeted plots. It is related to the shifting of grazing land from rangeland to forest area due to degradation of rangeland and reduction of plant growth. It can be concluded that there is a lack of regeneration in this forest due to increasing effect of grazing.

Conflict of Interests

The authors declare no conflict of interests.

Authors' Contribution

U.Ts. performed the plant study and drafted the manuscript; B.T., A.Ch., Kh.M., O.Sh., A.P., and B.A conducted related hydrobiology, forest, climate plant, soil study and processed experimental data, T.D. analysed data and worked on ArcGIS, O.M. wrote paper with input from all authors and commented on the manuscript.

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