Diversity of steppe soils of Transbaikalia (exemplified by the Daurskii Reserve)

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Abstract. The paper presents the study of soil cover of the steppe areas on the territory of the Daursky Biosphere Reserve in the Transbaikal Territory. Natural factors of soil formation are as follows: poorly dissected relief; arid and cryarid climate; shallow ground waters; steppe vegetation with a predominance of halophytes. The carbonate and salinity of the parent rocks contribute to the formation of various types of soils. We determined the types of soils in the study area according to the modern classification: Chestnut typical and saline, Saline gleyed typical and sulfide (sor) typical. Typical chestnut soils are formed on the tops of lake terraces and form complexes with saline soils. Salted chestnut soils occupy transit landforms. Saline soils are confined to low relief forms, the shoreline to the bottom of the lake, where the accumulation of readily soluble salts occurs. Typical Chestnut and saline soils are characterized by a light granulometric composition and a low humus content. Salted chestnut soils contain high concentrations of readily soluble salts in the profile. Saline (sulphide) and typical gleyed have a heavier granulometric composition, a highly alkaline reaction of the medium, a very low humus content and a high content of readily soluble salts. Physicochemical properties of soils reflect their genesis and the current state of these soils.

1. Introduction
The State Natural Biosphere Reserve Daurskii was founded in 1987. It is located on the territory of the Ononskii and Borzinskii districts of the Transbaikal Territory. In the south, the reserve borders Mongolia and consists of nine cluster sites, one of them, the Lake Barun-Torei site and adjacent steppes is the largest in area (44.7 thou ha) [1]. The terrain is characterized by weak dissection, relatively low altitude (100–150 m above the lake level) and plane surfaces occupied by accumulative forms. Linearly elongated and equally oriented landforms along the northern edge of the Barun-Torei basin indicate tectonic disturbances [2, 3, 4]. The climate is sharply continental with insufficient moisture, permafrost islands, negative average annual soil temperatures and an abundance of sunny days. Humidification of the territory is subject to pronounced cycles lasting about thirty years; they also determine the periodicity of drying out and filling up of steppe lakes [1, 5, 6]. According to geobotanical zoning, the territory belongs to the steppe region of Eurasia, the Central Asian (Dauro-Mongolian) subregion, the Mongolian steppe province of the East Mongolian sub-province and is genetically related to the steppe landscapes of Mongolia [7, 1]. The area under study belongs to the
dry steppe zone of dark chestnut and chestnut soils of the Transbaikal plain province and the Torei plain district [8].

A few details about the soils of Transbaikalia [9, 10, 11], as well as the changing climatic situation, in particular, the aridization of the climate, have determined the purpose of the work - to study the soil cover that forms around the dried-up Lake Barun-Torei.

2. Materials and Methods

We researched the area in 2013, during the arid phase of the climatic cycle, when the lake remained completely dry for four years. Soils under steppe vegetation, forming near Lake Barun-Torei on the southwest coast, near the state border with Mongolia have become a focus of our research.

We used the transect-catena method to study soil diversity and the patterns of soil distribution in space (figure 1). We laid seven soil profiles from the top of the weakly pronounced lake terrace up to the bottom of the dried-up lake. Physicochemical properties of soils are determined using methods generally accepted in soil science. In the laboratory, we determined the particle size distribution by the method of N.A. Kachinskii, actual acidity (pHwater) by potentiometric method, humus content by I.V. Tyurin, and the content of carbonates by the method of F.I. Kozlovskii [12; 13]. To determine the content of readily soluble salts, we used the analysis of a water extract with a soil to water ratio of 1: 5 [14]. Soil types are determined according to the “Classification of Russian Soils” (2004), which corresponds to the classification of soils in the international base WRB [15].

The figure presents photographs of soil sections, showing the change in genetic horizons.

Figure 1. Soil sections of the transect-catena on the southwestern shore of Lake Barun-Torei [16, 17, 18].

Morphological analysis provides detailed characteristics and diagnostics of soil types.

Section I-I is located on the plane surface of the lake terrace; Stipa kryloviiia dominates.

AJ 0-15 cm - chestnut with a yellowish tinge, dry, compacted, lumpy-powder-like soil structure, light loamy, penetrated with plant roots, no neoformations, gradual transition in color, noticeable by the abundance of roots, transition boundary is irregular and wavy.

BMK(s) 15-30 cm - chestnut with a yellowish tinge, fresh, compacted, lumpy structure, mean loamy, plant roots, detritus, carbonate cutans on detritus, carbonate impregnation, transition is noticeable in color and density, transition boundary is irregular and fine-wavy.
CAT(s) 30 cm and below - light chestnut, fresh, very compacted, single plant roots, parent rock yield, carbonate impregnation.

Soil: Chestnut typical, soil profile formula: AJ-BMK(s)-CAT(s).

Section I-2 is located on the southeastern slope terrace; *Stipa krylovii* dominates.

AJ(s) 0-10 cm - chestnut with a yellowish tinge, dry, compacted, lumpy-powder-like structure, light loamy, penetrated with plant roots, no neoformations, gradual transition in color, noticeable by the abundance of roots, transition boundary is irregular and wavy.

BMK(s) 10-21 cm - chestnut with a yellowish tinge, fresh, compacted, lumpy-powder-like structure, mean loamy, plant roots, detritus, carbonate cutans on detritus, carbonate impregnation, transition is noticeable in color and density, irregular boundary has a pocket-shape.

CAT(s) 21 cm and below - light chestnut, fresh, very compacted, single plant roots, parent rock yield, carbonate impregnation.

Soil: Chestnut typical, soil profile formula: AJ (s)-BMK (s)-CAT (s).

Section I-3 is located down the slope, on the plane surface near a small intermittent impounded body, *Stipa krylovii* dominates.

AJ(s) 0-16 cm - light chestnut, dry, loose, lumpy-powder-like structure, light loamy, penetrated with plant roots, rock fragments, no neoformations, gradual transition in color, noticeable by the abundance of roots, transition boundary is irregular and wavy.

BMK(s) 16-21 cm - chestnut with a yellowish tinge, fresh, compacted, lumpy-powder-like structure, medium loamy, plant roots, detritus, carbonate cutans on detritus, carbonate impregnation, transition is noticeable in color and density, irregular boundary has a pocket-shape.

CAT(s) 21-40 cm - light chestnut, fresh, very compacted; enclaves: single plant roots, parent rock yield and carbonate impregnation.

Cca,s 40 cm and below - whitish with a brownish tinge, very compacted, fresh, effervescence at 10% HCl, parent rock yield in the lower part of the horizon, carbonate sinter deposits on some parts of the rock

Soil: Chestnut typical, soil profile formula: AJ(s)-BMK(s)-CAT(s)-Cca,s

Section I-4 is located on the first levee of Lake Barun-Torei and dried-up bottom of intermittent impounded body. Sparse phytocenosis; mainly halophytes.

Skt 0-3 cm - salt crust.

Sg 3-16 cm - light gray, dry, loose, lumpy-powder-like structure, light loamy, penetrated with plant roots, stones, no neoformations, no effervescence at 10% HCl, transition is gradual in color, noticeable by the abundance of roots, transition boundary is irregular and wavy.

SSg 16-27 cm - light gray with a yellow tinge, fresh, compacted, lumpy-powder-like structure, medium loamy, enclaves: plant roots, no neoformations, no effervescence at 10% HCl, transition is noticeable in color and density, transition boundary is irregular and wavy.

Gs 27 cm and below - gray-yellow, fresh, very compacted, enclaves: single plant roots, parent rock yield, BUT: no effervescence at 10% HCl.

Soil: Sulphide (sor) solonchak typical, soil profile formula: Skt-S (g) 1-S (g) 2-SSg-Gs, ca

Section I-5 is located between the first and second levees of Lake Barun-Torei.

AJ 0-11 cm - light chestnut, dry, compacted, lumpy-silty structure, light loamy, penetrated with plant roots, stones, no neoformations, no effervescence at HCl, transition is gradual in color, noticeable by the abundance of roots, density, irregular transition boundary is wavy.

AJ(s) 11-28 cm - light chestnut with a yellowish tinge, fresh, compacted, lumpy-silty structure, light loamy, plant roots, no neoformations, and no effervescence at 10% HCl, transition is noticeable in color and density, irregular border is wavy.

BMK(s),ca 28-40 cm - light chestnut with a brownish tinge, fresh, compacted, lumpy-silty structure, light loamy, single plant roots, enclaves: single plant roots, neoplasms: carbonate impregnation, effervescence at 10% HCl.
CAT(s) 40 cm and below - light brown, fresh, compacted, lumpy structure, light and medium loamy, single plant roots, detritus, neoformations: carbonate impregnation, violent effervescence at 10% HCl.

Soil: Chestnut salted, soil profile formula: AJ1ca-AJ (s), ca-BMK (s), ca.

Section I-6 is located at the top of the second levee of Lake Barun-Torei. Sparse phytocenosis.

AJ 0-10 cm - light chestnut, fresh, compacted, lumpy-silty structure, light loamy, abundant roots of herbaceous plants, no neoformations, gradual transition in color and plant roots, irregular border is wavy.

AJ(s), ca 10-36 cm - chestnut, fresh, compacted, lumpy-granulation structure, light and medium loamy, plant roots, small fragments of rock, no neoformations, gradual transition in color and density.

BMK1s, ca 36-43 cm - light chestnut, fresh, compacted, lumpy-powder-like structure, light loamy, small stones, gravel stones, single plant roots, no neoformations, transition is noticeable in color, irregular border has pocket-shape.

BMK2s 43-50 cm – pale with a yellowish tinge, fresh, compacted, lumpy-silty weak structure, light loamy - sandy loamy, small fragments of rock, detritus, sand of various sizes, no neoformations, gradual transition in color, irregular border is wavy.

Cs, ca 50 cm and below - pale with a pinkish tinge, fresh, loose, fine lumpy structure, sandy loamy, enclaves: sand of various sizes, detritus, rock debris, and no neoformations.

Soil: Chestnut salted, soil profile formula AJ (s), ca-AJ1s, ca-BMK1s1, ca-BMK2s-Cs, ca.

Section I-7 is located on the plane bottom surface of the dried-up Lake Barun-Torei. *Suaeda corniculate*, a one-year halophyte, prevails.

Skt 0-3 cm - compacted whitish crust

S 3-18 cm - gray with a yellowish tinge, fresh, compacted, dusty-powder-like structure, medium loamy, single plant roots, no neoplasms, transition is gradual in color, transition boundary is irregular and fuzzy.

SSf,g 18-40 cm - gray with red vertical stripes, moist, compacted, lumpy-powder-like structure, medium-heavy loamy, no enclaves, neoplasms: ochreous ferruginous patches, gradual transition in color, irregular border with cutans.

Gs,f 40-70 cm - brownish yellow with red stripes, moist, compacted, lumpy-powder-like structure, heavy loamy, no enclaves, no neoformations: ochreous spots and lenses of oxidized iron.

Soil: Sulphide saline (sor) typical, soil profile formula: Skt-S-SSfe, g-Gs, f.

### 3. Results and Discussion

Chestnut typical soils (sections I-1, I-2, and I-3) are predominant, forming under feather grass phytocenosis on gentle elevations of lake terraces. The soil profile is incomplete; the grain-size structure is composed mainly by fractions of light loam and sandy loam. (table 1).

The humus content is low - up to 2.9%, the reaction of the environment is from acid-free to weakly alkaline, soils are slightly carbonate (table 2). The soils of these sections belong to postlithogenic trunk, accumulative-carbonate low-humus order, chestnut type; typical subtype AJ (s) -BMK(s) - CAT(s).

Chestnut saline soils (sections I-5 and I-6) are found in a combination with typical chestnut and saline soils. They form on transit landforms under steppe vegetation. The grain-size structure in the section I-5 is characterized by an increase in the content of the fine sand fraction in the middle part of the profile, and in the section I-6 the fine sand fraction predominates throughout the profile. The reaction of the environment in these sections is slightly alkaline, the humus content is up to 3.1%, and the soils are high-carbonate. Soil: trunk - postlithogenic, order - accumulative-carbonate low-humus, type – chestnut and subtype - salted: AJ1, ca-AJ2 (s), ca-BMK(s), ca-CAT(s).
Saline soils (sections I-4 and I-7) are formed in low relief forms and along the shoreline of the lake. The vegetation is represented by halophytes, with a predominance of *Suaeda corniculata*. The grain-size structure of saline soils is heavy, with a predominance of the silty fraction. The reaction of the environment is strongly alkaline; the salt profile is dominated by HCO$_3^-$ anions and Na$^+$ cations (table 2).
| Composi | Depth, cm | pH_{water} | C, org. % | CO_3^- | HCO_3^- | Cl | SO_4^{2-} | Ca^{2+} | Mg^{2+} | Na^+ | K^+  |
|----------|----------|------------|-----------|-------|--------|---|--------|-------|------|-----|-----|
| AJ       | 0-15     | 7.4        | 2.9       | 0.0   | 0.38   | 0.52 | 0.90   | 0.36  | 0.95 | 0.32 | 0.08 |
| BMK(s)   | 15-30    | 8.1        | 1.2       | 0.0   | 0.40   | 0.60 | 0.92   | 0.40  | 1.01 | 0.38 | 0.07 |
| CAT(s)   | 30 and below | 8.0   | 0.8       | 0.0   | 0.42   | 0.58 | 0.90   | 0.41  | 1.00 | 0.40 | 0.07 |
| AJ(s)    | 0-10     | 7.0        | 2.2       | 0.0   | 0.30   | 0.42 | 0.69   | 0.35  | 0.92 | 0.15 | 0.06 |
| BMK(s)   | 10-21    | 7.6        | 1.9       | 0.0   | 0.34   | 0.56 | 0.83   | 0.40  | 1.00 | 0.26 | 0.09 |
| CAT(s)   | 21 and below | 7.6    | 1.0       | 0.0   | 0.57   | 0.85 | 0.92   | 0.40  | 1.50 | 0.33 | 0.11 |
| AJ(s)    | 0-16     | 6.4        | 2.1       | 0.0   | 0.60   | 0.62 | 0.27   | 0.35  | 0.90 | 0.20 | 0.06 |
| BMK(s)   | 16-21    | 6.6        | 1.7       | 0.0   | 0.69   | 0.70 | 0.31   | 0.40  | 0.98 | 0.24 | 0.08 |
| CAT(s)   | 21-40    | 7.3        | 1.6       | 0.0   | 0.90   | 0.93 | 0.31   | 0.40  | 1.50 | 0.18 | 0.06 |
| Cca,s    | 40 and below | 7.5    | 1.4       | 0.0   | 0.78   | 0.83 | 0.22   | 0.36  | 1.30 | 0.12 | 0.05 |
| Skt      | 0-3      | 10.3       | 2.1       | -     | -      | -   | -      | -     | -  | -   | -   |
| Sg       | 3-10     | 10.2       | 0.5       | 0.0   | 12.41  | 2.25 | 5.23   | 5.10  | 2.28 | 12.53 | 1.18 |
| SS(g)    | 10-20    | 10.2       | 0.3       | 0.52  | 10.42  | 2.30 | 5.28   | 5.22  | 2.10 | 10.59 | 0.96 |
| 20-30    | 10.3     | 0.3       | 0.52     | 10.40 | 2.22   | 5.28 | 5.20   | 1.90  | 10.56 | 0.89 |
| 30-40    | 10.3     | 0.2       | 0.53     | 10.65 | 0.82   | 3.32 | 3.28   | 0.91  | 9.62  | 0.82 |
| Gs       | 40-50    | 10.3       | 0.2      | 0.23  | 8.70   | 0.81 | 3.35   | 4.33  | 0.88  | 8.66  | 0.81 |
| 50-60    | 10.3     | 2.1       | 0.23     | 9.72  | 0.82   | 4.37 | 4.35   | 0.62  | 9.66  | 0.71 |
| AJ       | 0-11     | 7.4        | 1.4       | 0.0   | 0.12   | 0.34 | 0.72   | 0.18  | 0.05 | 0.65 | 0.12 |
| AJ(s)    | 11-28    | 7.5        | 1.4       | 0.0   | 0.16   | 0.42 | 0.81   | 0.20  | 0.08 | 0.84 | 0.28 |
| BMK(s),ca| 28-40    | 8.0        | 1.0       | 0.0   | 0.41   | 0.76 | 1.35   | 0.25  | 0.16 | 1.58 | 0.53 |
| CAT(s)   | 40 and below | 8.0    | 1.4       | 0.0   | 0.57   | 0.85 | 0.92   | 0.40  | 1.50 | 0.61 | 0.20 |
| AJ(ca)   | 0-10     | 6.4        | 3.1       | -     | -      | -   | -      | -     | -  | -   | -   |
| AJ(s)    | 10-36    | 7.5        | 1.0       | 0.0   | 0.66   | 0.42 | 0.73   | 0.40  | 0.80 | 0.46 | 0.15 |
| BMK1s,ca | 36-43    | 6.7        | 1.0       | 0.0   | 0.62   | 0.34 | 0.46   | 0.30  | 0.70 | 0.31 | 0.10 |
| BMK2s    | 43-50    | 6.7        | 0.5       | 0.0   | 0.49   | 1.38 | 0.69   | 0.40  | 2.00 | 0.12 | 0.04 |
| Cs,ca    | 50 and below | 7.9    | 0.7       | 0.0   | 0.44   | 1.38 | 0.94   | 0.45  | 1.50 | 0.61 | 0.20 |
| Skt      | 0-3      | 9.9        | 0.7       | -     | -      | -   | -      | -     | -  | -   | -   |
| S        | 3-10     | 9.9        | 0.9       | 0.08  | 1.00   | 0.96 | 2.40   | 0.20  | 0.30 | 2.95 | 0.98 |
| SSf,g    | 10-20    | 10.0       | 0.5       | 0.07  | 2.90   | 1.24 | 5.10   | 0.20  | 0.30 | 6.61 | 2.20 |
| 20-30    | 9.9      | 0.3       | 0.70     | 2.02  | 1.58   | 4.83 | 0.20   | 0.20  | 6.55 | 2.18 |
| 30-40    | 9.9      | 0.5       | 0.57     | 2.20  | 0.91   | 3.25 | 0.20   | 0.66 | 4.55 | 1.52 |
| 40-50    | 9.9      | 0.5       | 0.50     | 2.50  | 0.51   | 3.38 | 0.30   | 0.74 | 4.38 | 1.46 |
| Gs,f     | 50-60    | 9.9       | 0.7       | 0.20  | 1.00   | 0.51 | 2.81   | 0.20  | 0.49 | 2.87 | 0.96 |
| 60-70    | 9.9      | 0.9       | -        | -     | -      | -   | -      | -     | -  | -   | -   |

<|> – not defined
The chemical mechanism is defined as soda-sodium sulfate. Soil of section I-4: trunk - postlithogenic, order - halomorphic, type - sulphide saline (gleyed) typical and subtype - typical: Skt-Sg - Sg-Gs, ca. For section I-7: type - Sulphide saline (sor; subtype - typical: Skt-S (g) I-S (g) 2-SSg-Gs, ca.

4. Conclusion

1. Features of soil formation in the steppes of Transbaikalia and pedohalogenesis are mainly determined by natural conditions: the degree of relief dissection (weakly dissected relief), various lithological composition, which determines the soil texture, extremely continental arid climate, exudational regime, chemical composition and mineralization of ground and lacustrine waters.

2. The variety of soils in the structure of the soil cover is manifested in all types of soils from chestnut to saline. Chestnut typical soils are predominant, saline chestnut soils occupy transitional landscapes, and saline soils - solonchaks - are formed in the lower parts of the terraces and the edge and on the dried bottom of Lake Barun-Torei.

For the soils, the following indicators are characteristic: reaction of the environment from slightly alkaline to strongly alkaline, the presence of carbonate neoformation, low humus content, and the predominance of the fraction of sand in chestnut soils and silt in saline soils. In salted soils, the soda-sulphate sodium type of salinization is noted.

References

[1] Kirilyuk O K, Kirilyuk V E, Goroshko O A, Saraeva L I, Sinitsa S M, Borodina T I, Tkachenko E E and Brinikh V A 2009 Biosphere reserve “Daurskii” (Chita: Express-publishing) p 104
[2] Voskresenskii S S 1962 Geomorphology of Siberia (Moscow: MSU) p 352
[3] Shamsutdinov V Kh 1975 Cenozoic history of southeastern Transbaikalia (on the example of the Torei and East Torei depressions) Bulletin of the Commission for the Study of the Quaternary Period 44 pp 89-96
[4] Bazhenova O I, Kobylkin D V, Makarov S A, Rogaleva N N, Silaev A V and Cherkashina A A 2015 Reconstruction of aeolian processes in the Daurian steppes in arid phases of relief formation Geogr. Natur. Resour. 3 pp 126-137
[5] Obyazov V A and Zhuldybina T V 2011 Dependence of changes in the chemical composition of the water of the rivers of the Transbaikal Territory on the value of the river flow Bulletin of the Transbaikal State University 8 pp 97-103
[6] Dubynina S S 2017 Climatic fluctuations and changes in the reserves of green mass in the steppes of South-Eastern Transbaikalia Advances in current natural sciences 5 pp 95-100
[7] Tkachuk T E and Zhukova O B 2013 Dynamics of vegetation of the Daurskii reserve Uchenye Zapiski ZabGU 1 pp 46-57
[8] Atlas of Chita oblast and the Aginskii Buryat district 1997 ed VS Kulakov (Moscow: Roskartografiya) p 48
[9] Nogina N A 1964 Soils of Transbaikalia (Moscow: Nauka) p 315
[10] Chernousenko G I and Yannova I A 2003 Saline soils of the island cryoarid steppes of Transbaikalia Steppes of Northern Eurasia Reference steppe landscapes: problems of protection, ecological restoration and use (Orenburg) pp 557-559
[11] Lopatovskaya O G, Tkachuk T E, Saraeva L I, Podimakhina O A, Minakov K K and Tchausov D G 2012 Saline soils of the Daurskii State Biosphere Reserve Proc Socio-economic and environmental problems and prospects of international cooperation Russia-China-Mongolia (Chita: Chernyshevskii ZGPSU) pp 26-31
[12] Vorobyeva L A 2006 Theory and practice of chemical analysis of soils (Moscow: GEOS) p 400
[13] Kachinskii N A 1958 Mechanical and microaggregate soil composition, methods of its study (Moscow: Publishing house of the Academy of Sciences of the USSR) p 93
[14] Bazilevich N I and Pankova E I 1968 Experience of soil salinity classification Pochvovedenie
11 pp 3-15

[15] Classification and diagnostics of soils in Russia 2004 ed L L Shishov et al (Smolensk: Oikumena) p 342

[16] State Geological Map of the Russian Federation Aldan-Transbaikal series 2010 Sc. 1: 1 000 000 (Saint Petersburg: VSEGEI) p 554

[17] Eastern Transbaikalia (Prospects for the development of the productive forces of the Chita region) 1968 (Irkutsk East-Siberian Book. Publishing house) p 186

[18] Geology of the USSR Chita region 1961 Part 1 (Moscow: GNTIL on Geology and Subsoil Protection) p 548