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APPLIED PROBLEMS OF ARID LANDS DEVELOPMENT

Specific Features of the Spatial Distribution Pattern of Vegetation in the Eastern Part of the Zaisan Depression

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Abstract—The spatial regularities of the plant cover in the eastern part of the Zaisan Depression were analyzed on three ecological profiles. In the piedmont plains of the Kurshum and Manrak Ridges, the distribution pattern of plant communities is determined by the altitude above sea level, mesoelements of the topography, the formation rate of the soil cover, and the salinity of soils and soil-forming rocks. Plant communities in the Black Irtysh River Sands are formed with respect to the relief, age, and wind redeposition of sands; soil salinization in the depressions between levees; and groundwater depth and mineralization.

Keywords: Zaisan Depression, piedmont plains, vegetation, spatial regularities

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INTRODUCTION

The Zaisan Depression is located between the ridges of the Altai Mountains in the north and the Saur-Manrak-Tarbagatai Ridges in the south. The ring-like zonal structure here is determined by complicated inversion processes that affect the weather in the depression and around it. The central lowland part is occupied by desert ecosystems. The piedmont areas are represented by desert steppes. The variability of landscapes and ecological conditions of the Zaisan Depression is responsible for the diversity of the flora and vegetation of the region. The flora of the area has been rather comprehensively studied (Aralbaev, 1998) and is characterized by a high percentage of endemic plant species.

According to the botanical-geographical zoning (Rachkovskaya et al., 2003), the vegetation of the Zaisan Depression is assigned to the Dzhungar province of the Iran-Turan subregion of the Sakhara-Gobi desert region. The zonal vegetation belongs to northern deserts.

The first data on the plant cover of the Zaisan Depression appeared in materials published at the beginning of the 20th century (Sedel'nikov, 1910; Sapozhnikov and Shishkin, 1916, Borisova, 1935). The subsequent research was fragmentary. The plant cover of the left bank of the Black Irtysh River sands, the *Calligonum* spp. communities in particular, was comprehensively studied by Kurochkina (1962, 1966, 1978). Later, the scientist made a brief characterization of *Haloxylon ammodendron* communities (Kurochkina, 2003). There are also small-scale geobotanic maps (*Atlas*…, 1982; *Karta*…, 1995; *Natsional'nyi atlas*…, 2006) that merit attention.

The insufficiency of the data on the plant cover of this region has required its inventory. The studies in the Zaisan Depression were performed according to the program of basic research of the Ministry of Education and Science of the Kazakhstan Republic in 2009–2011. The research data have been published (Dimeyeva et all., 2011; Kedryashkin et all., 2012; Sultanova et all., 2012; Islamgulova and Sultanova, 2012; Permitina, 2013). The articles include a description of the soil cover, the analysis of ecologic-physiognomic vegetation types, and characterization of steppe vegetation of the piedmont plains. The results of the study of the Kuludzhun Sands (the western part of the Zaisan Depression) with relict pines and juniper shrubs (*Juniperus sabina*) are discussed for the first time. This article mainly concerns the regularities of the spatial distribution pattern of vegetation in the eastern part of the Zaisan Depression.

MATERIALS AND METHODS

The plant cover pattern was studied by the traditional methods of field geobotany (*Polevaya*..., 1959–1976). Three geobotanic profiles—in the southeastern (Tugyl) and northeastern (Amanat) parts of the Zaisan Depression and on the Bozaigyrkum (Kabyrgatal) sand massif assigned to the Black Irtysh sands—were laid (Fig. 1). The plant names are given according to Cherepanov (1995), except for the species of *Calligonum* genus, which were determined by the *Flora of Kazakhstan* (*Flora Kazakhstana*..., 1960) and the

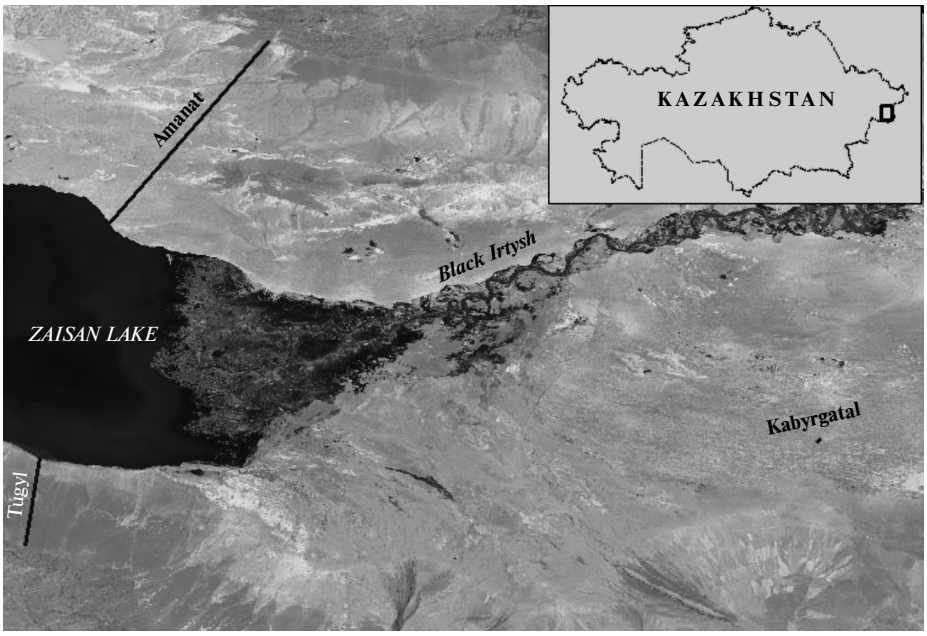

Fig. 1. Geographical position of the studied area.

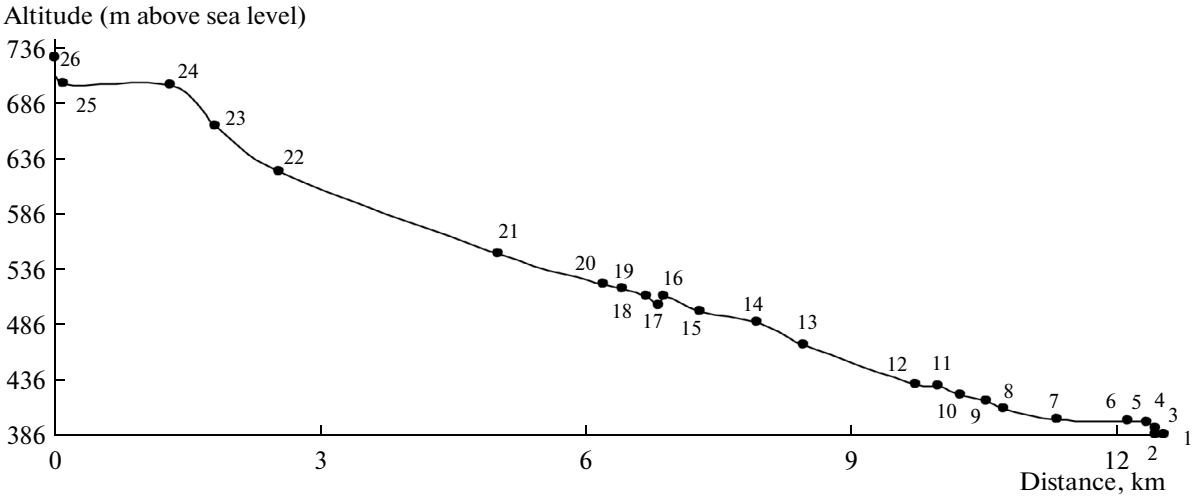

Fig. 2. The Tugyl ecological profile: 1–26—plant communities on the profile (explication is given in Table 1).

Illustrated Guide for Identification of the Plants of Kazakhstan (*Illyustrirovannyi*..., 1969).

RESULTS

The Tugyl Ecological Profile (the Piedmont Plain of the Manrak Ridge)

The Tugyl ecological profile stretches from the shoreline of the Zaisan Lake at an altitude of 386 m to the branches of the Manrak Ridge at an altitude of 726 m (Fig. 2, Table 1). The length of the profile is 12.6 km. It crosses the lake terraces and piedmont valley. The soil cover of the lake terraces is formed by marshy, meadow-marshy, and meadow soils. On the piedmont valley, brown desert solonetzic and brown desert poorly formed stony soils are widespread; meadow-brown stony soils, meadow solonchaks, and desert stony solonetzes also occur. The soil surface is covered by crushed stone, the amount of which rises towards the mountains. The spatial pattern of the intrazonal vegetation on the lake terraces is characterized by concentric ecological microbelts of plant communities.

Reed marshes, which previously formed a continuous belt in the bank zone, are now fragmentary. They are composed of *Scirpus lacustris*, *Bolboschoenus maritimus*, and *Typha latifolia*. At the low lake terrace near the water line, the reed stands include *Glaux maritima*, *Lactuca tatarica*, and *Batrachium circinatum*. *Rumex*

Table 1. Vegetation of the Tugyl ecological profile

Community number	Altitude (m above sea level)	Vegetation	Mesorelief	Soils
1	386	Reed (*Phragmites australis*)	Low lake terrace	Marshy
2	387	Dock (*Rumex aquaticus*)	Low lake terrace	Meadow-marshy
3	388	Cattail (*Typha laxmannii)*	Low lake terrace	Meadow-marshy
4	393	*Pseudosophora alopecuroides*–grass (*Calamagrostis epigeios* and *Elytrigia repens*) with *Argusia sibirica*	Low lake terrace	Saline meadow
5	398	*Achnatherum splendens*	Low lake terrace	Meadow solonchakous
6	399	*Anabasis salsa* with sagebrush (*Artemisia pauciflora*)	High lake terrace	Stony solonetzic brown desert
7	401	*Anabasia salsa* and *A. aphylla* with *Climacoptera brachiata*	High lake terrace	Stony solonetzic brown desert
8	410	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) with *Anabasis aphylla* and *Parmelia vagans*	Low part of the piedmont gently inclined plain	Stony solonetzic brown desert
9	417	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) with *Anabasis aphylla*	Low part of the piedmont gently inclined plain	Stony solonetzic brown desert
10	423	Sagebrush–feather-grass (*Stipa sareptana* and *Artemisia terrae-albae*) with *Anabasis aphylla*	Low part of the piedmont gently inclined plain	Stony ordinary brown desert
11	431	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) with *Anabasis aphylla* and *Parmelia vagans*	Low part of the piedmont gently inclined plain	Stony solonetzic brown desert
12	433	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) with *Anabasis aphylla*	Low part of the piedmont gently inclined plain	Stony solonetzic brown desert
13	468	Sagebrush (*Artemisia terrae-albae*, *A. pauciflora*, and *A. sublessingiana*)	Low part of the piedmont gently inclined plain	Stony solonetzic brown desert
14	488	Sagebrush (*Artemisia pauciflora*) with *Anabasis aphylla*	Middle part of the piedmont gently inclined plain	Stony solonetzic brown desert
15	498	*Anabasis salsa* with *Artemisia pauciflora*	Middle part of the piedmont gently inclined plain	Stony solonetzic brown desert
16	512	*Nanophyton erinaceum*	Middle part of the piedmont gently inclined plain	Stony solonetzic brown desert
17	504	*Atriplex cana* with *Achnatherum splendens*	Runoff depression	Solonetzic meadow solonchak
18	511	*Atriplex cana*	Depression	Stony solonchakous desert solonetz
19	519	Sagebrush (*Artemisia pauciflora*) with *Nanophyton erinaceum* and *Anabasis salsa*	Middle part of the piedmont gently inclined plain	Stony solonetzic brown desert
20	523	Sagebrush (*Artemisia pauciflora*) with *Anabasis salsa* and *A. aphylla*	Middle part of the piedmont gently inclined plain	Stony solonetzic brown desert

Table 1. (Contd.)

Community number	Altitude (m above sea level)	Vegetation	Mesorelief	Soils
21	550	Sagebrush–feather-grass–fescue (*Festuca valesiaca*, *Stipa capillata*, and *Artemisia sublessingiana*)	Middle part of the piedmont gently inclined plain	Stony ordinary brown desert
22	624	Fescue-sagebrush (*Artemisia sublessingiana* and *Festuca valesiaca*)	Top part of the piedmont gently inclined plain	Stony ordinary brown desert
23	665	Feather-grass–fescue–sagebrush (*Artemisia sublessingiana*, *Festuca valesiaca*, and *Stipa capillata*)	Western slope to the runoff depression	Stony poorly formed brown desert
23 A	700	Bushy (*Caragana pumila* and *Spiraea hypericifolia*)	Runoff depression	Meadow-brown
24	702	Feather-grass–fescue–sagebrush (*Artemisia sublessingiana*, *Festuca valesiaca*, and *Stipa capillata*) with *Spiraea hypericifolia*	Western slope to the runoff depression	Stony poorly formed brown desert
25	703	Bushy (*Caragana pumila* and *Spiraea hypericifolia*)	Runoff depression	Meadow-brown
26	726	Sagebrush (*Artemisia gracilescens*) with bunch grasses (*Festuca valesiaca* and *Stipa capillata*)	Top part of the piedmont gently inclined plain, ridge foot	Stony poorly formed brown desert

aquatic, which is widespread here, creates a bright red-brown aspect.

The *Rumex aquatic* belt gives way to hygrophyte communities characterized by great species diversity (*Typha laxmannii*, *Juncus articulatus*, *Carex appendiculata*, *Sparganium stoloniferum*, *Butomus umbellatus*, *Alisma lanceolata*, and others). The formation of halophyte-grass (*Puccinellia dolicholepis*, *Aeluropus littoralis*, and *Hordeum brevisubulatum*) and mesophyte-grass (*Calamagrostis epigeios* and *Elytrigia repens*) vegetation is related to the soil salinity and varies in space and with time.

The higher level is occupied by grass-forbs coenoses. Mesophyte-grass–forbs meadows (*Glycyrrhiza glabra*, *Sphaerophyza salsula*, *Leymus multicaulis*, and *Bromopsis inermis*) are often replaced by halophyte communities with the participation of *Artemisia nitrosa*, *A. schrenkiana*, *Aeluropus littoralis*, *Saussurea amara*, and *Limonium otolepis*. Cheegrass (*Achnatherum splendens*) communities are represented almost all over at the next level. They form tall-grass meadows in large areas in the deltas of the rivers entering the Zaisan Lake. Similar meadows are often seen on the high floodplain terraces of the Kal'dzhir, Black Irtysh, and Karatal rivers. They often include *Halimodendron halodendron*, *Halimione verrucifera*, *Glycyrrhiza uralensis*, *Leymus angustus*; halophytic forbs (*Saussurea salsa*, *Plantago maritima*, and *Limonium gmelinii*); halophytic grasses (*Aeluropus littoralis*, *Puccinellia dolicholepis*, and *P. tenuissima*), and annual saltwort (species of the *Salsola*, *Suaeda*, *Climacoptera*, and *Petrosimonia* genera). There are small spots of *Camphorosma monspeliaca* and *Halimione verrucifera* communities. The high lake terrace is characterized by the sequence of *Atriplex cana* communities on meadow solonchaks and *Artemisia pauciflora* and *Anabasis salsa* communities on desert solonetzes.

At altitudes above 410 m, the lake terraces are bordered by the piedmont plains. Coenoses of *Artemisia pauciflora*, *Anabasis salsa*, and *Atriplex cana* are distributed here. Communities of *Nanophyton erinaceum* occur in association with them. The plant cover is disturbed by grazing in places. Upon pasture degradation, *Ceratocarpus utriculosus* and *Artemisia austriaca* appear in the plant cover of the piedmont plains. Sagebrush-bunch grass communities (*Stipa capillata*, *Festuca valesiaca*, and *Artemisia sublessingiana*) reach the altitude of 550 m above sea level. The ratio between the bunch grasses varies sometimes with respect to edaphic conditions, and *Festuca valesiaca*, *Stipa sareptana*, and *Stipa orientalis* predominate. The most widespread species are *Koeleria cristata* and *Kochia prostrata*. At the end of the profile in the piedmont of the Manrak Mountains (726 m), the fescue-sagebrush community (*Artemisia gracilescens*, *Festuca valesiaca*, and *Stipa sareptana*) is formed. It is characterized by the presence of typical steppe plants (*Iris scariosa* and *Ancanthya igniaria*). The beds of temporary water streams create heterogeneity of the the piedmont valley plant cover. Bush communities (*Spiraea hypericifolia*, *Caragana pumila*, and *C. frutex*) are formed in the run-off depressions.

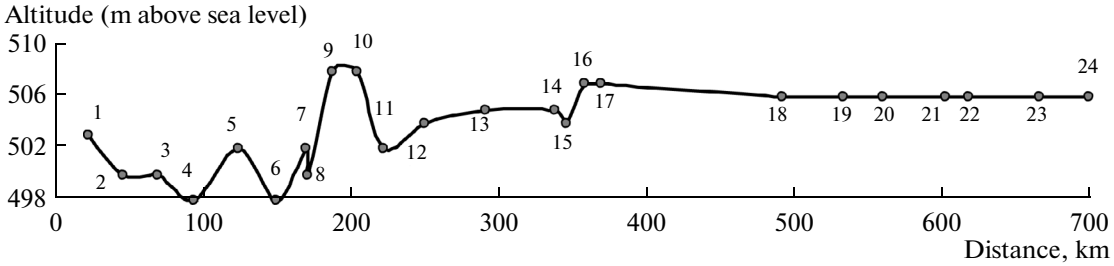

Fig. 3. The Kabyrgatal ecological profile: 1–24—plant communities on the profile (explication is given in Table 2).

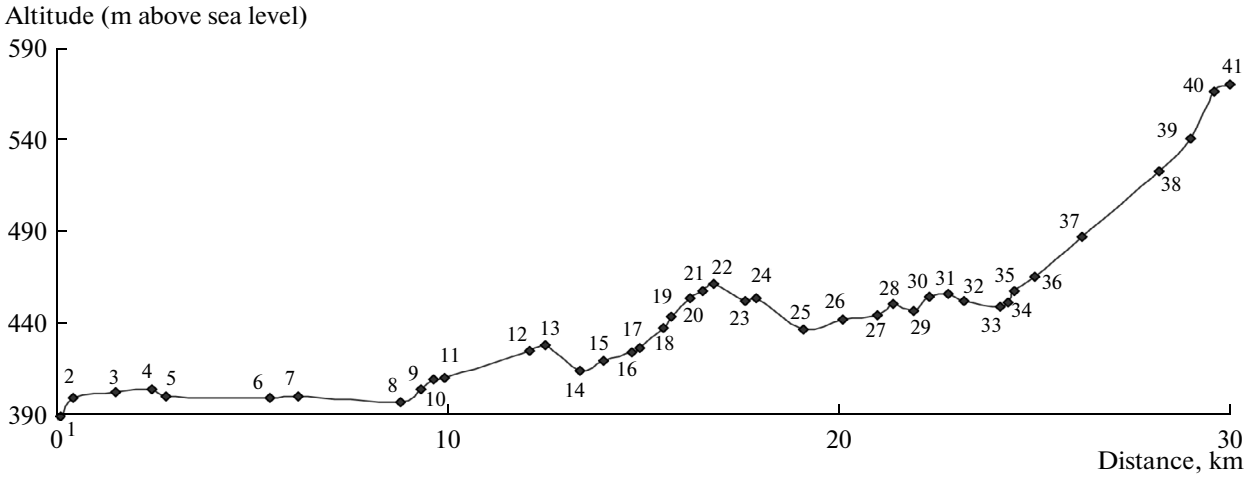

Fig. 4. The Amanat ecological profile: 1–41—plant communities on the profile (explication is given in Table 3).

The Kabyrgatal (Black Irtysh Sands) Ecological Profile

The sand massifs on the left bank of the Black Irtysh River are named Bozaigyrkum, Taskum, Akzhan, and Akkum. With respect to the features of topography, they are assigned to two massifs: the northern sandy and sandy loamy Akzhan Plain and hilly-barkhan sands in the southern part. The Black Irtysh sands are characterized by a relatively high position: 410–640 m above sea level. The area is represented by a piedmont plain sloping to the north-northwest, towards Zaisan Lake and the Black Irtysh River. The elevated areas are represented by barkhan sands not fixed by vegetation. They are surrounded by hilly sands, which are usually low (5–10 m) and are sometimes crossed by valley-like depressions. Sands with small lakes and reed meadows in depressions (churoty) are spread along the edge of hilly sands in the southern part of the massif (Kurochkina, 1962).

The ecological profile is set on the Bozaigyrkum sand massif in the Kabyrgatal area (Fig. 3, Table 2). The sand massif is assigned to the hilly-ridge sands. The sand ridges stretch from the northwest to the southeast. The profile is set transverse one of them. It begins in the *Populus diversifolia* grove on the leveled sands; crosses the depression between sand ridges, hilly sands, and the following depression between ridges; and ends near the new sand ridge. The total length of the soil profile is 700 m.

The leveled and gently sloping sands are occupied by sedge-wormwood (*Artemisia arenaria* and *Carex pachystilis*) and *Spiraea hypericifolia* communities. Communities of *Calligonum* spp. are formed on the summits of the hilly sands. The *Artemisia arenaria* associations are allocated to small-hilly and hilly sands. The participation of reed as a subdominant of the plant communities points to more favorable moistening conditions on the slopes or at the foots of sand hills. In the *Artemisia arenaria* communities formed in blowouts, the participation of *Chondrilla ambigua*, *Stipagrostis pennata*, and *Corispermum hyssopifolium* rises. Groundwater in the depressions between the sand ridges is mineralized and not deep. Under these conditions, halophyte-forbs and halophyte–dwarf-semishrub (*Halimione verrucifera* and *Camphorosma monspeliacum*) communities develop. The depressions between sand hills are characterized by special ecological conditions. Fresh groundwater is not deep, and the surface water of atmospheric precipitation drains into them. Small groves of poplar (*Populus laurifolia*), birch (*Betula microphylla*), and willow with bushes (*Halimodendron halodendron*, *Rosa laxa*, and *Lonicera*

Table 2. Vegetation of the Kabyrgatal ecological profile

Community number	Altitude (m above sea level)	Vegetation	Relief	Soils
1	503	Poplar (*Populus diversifolia*)	Leveled depression	Plain sands
2	500	Sedge-wormwood (*Artemisia arenaria* and *Carex pachystilis*)	Leveled depression	Plain sands
3	500	*Spiraea hypericifolia*	Depression	Plain sands
4	500	Halophyte-dwarf-semishrub–grass–wormwood (*Artemisia nitrosa*, *Leymus racemosus*, *Camphorosma monspeliacum*, and *Kochia prostrata*)	Depression between ridges	Meadow-desert sands
5	502	Halophyte-forbs (*Artemisia nitrosa, Limonium gmelinii, Plantago salsa,* and *Saussurea salsa*)	Depression between ridges	Meadow-desert sands
6	498	Halophyte-forbs wormwood (*Artemisia nitrosa*, *Saussurea salsa*, and *Limonium gmelinii*)	Depression between ridges	Meadow-desert sands
7	502	Bushy (*Halimodendron halodendron* and *Spiraea hypericifolia*)	Hill foot	Meadow-desert sands
8	500	Wormwood with bushes (*Artemisia arenaria*, *Halimodendron halodendron*, and *Calligonum membranaceum*)	Northeastern hill slope	Hilly sands
9	508	*Calligonum sinuoso-aculeolatum* with wormwood (*Artemisia arenaria*)	Hill summit	Hilly sands
10	508	Wormwood (*Artemisia arenaria*)	Southwestern slope	Hilly sands
11	502	Wormwood (*Artemisia arenaria*) with *Leymus racemosus*	Blowout	Hilly sands
11 A	505	Reed-wormwood (*Artemisia arenaria* and *Phragmites australis*)	Northeastern hill slope	Hilly sands
11 B	501	Poplar-willow (*Salix* sp. and *Populus laurifolia*) with *Lonicera tatarica*	Depression between hills	Meadow-desert sands
11 C	501	Honeysuckle-willow (*Salix* sp. and *Lonicera tatarica*) with *Rosa laxa*	Depression between hills	Meadow-desert sands
12	504	Wormwood (*Artemisia arenaria*) with *Phragmites australis* and *Calligonum sinuoso-aculeolatum*	Slightly pronounced elevation	Small-hilly sands
13	505	Wormwood–salt-tree (*Halimodendron halodendron* and *Artemisia arenaria*) with *Populus laurifolia* and *Salix* sp.	Depression between hills	Meadow-desert sands
13 A	500–498	Willow (*Salix* sp.) with *Betula microphylla*	Depression between hills	Meadow-desert sands
13 B	501–497	Briar–salt-tree (*Halimodendron halodendron* and *Rosa laxa*) with *Betula microphylla*	Depression between hills	Meadow-desert sands
14	505	*Calligonum dissectum* with *Artemisia arenaria* and *Chondrilla ambigua*	Hill summit	Barkhan sands
15	504	Sand wormwood (*Artemisia arenaria*)	Depression, blowout	Hilly sands

Table 2. (Contd.)

Community number	Altitude (m above sea level)	Vegetation	Relief	Soils
16	507	Wormwood–salt-tree (*Halimodendron halodendron* and *Artemisia arenaria*) with *Populus laurifolia* and *Salix* sp.	Hilly sands	Hilly sands
17	506	Halophyte-forbs (*Artemisia nitrosa*, *Saussurea salsa*, and *Limonium gmelinii*)	Depression between ridges	Meadow-desert sands
18	–	Halophyte-forbs (*Plantago salsa*, *Saussurea salsa*, *Limonium gmelinii*, and *Glycyrrhiza uralensis*)	Depression between ridges	Meadow-desert sands
19	–	Sagebrush (*Artemisia nitrosa*)	Depression between ridges	Meadow-desert sands
20	–	Halophyte-forbs (*Phragmites australis*, *Saussurea salsa*, and *Euphorbia lamprocarpa*)	Depression between ridges	Meadow-desert sands
21	–	*Halimione verrucifera*	Depression between ridges, fallow	Meadow-desert sands
22	–	Plantain–camphor-fume (*Camphorosma monspeliacum* and *Plantago salsa*)	Depression between ridges	Meadow-desert sands
23	–	Busy (*Spiraea hypericifolia*)	Hill foot	Meadow-desert sands
24	506	Wormwood (*Artemisia arenaria*)	Northeastern hill slope	Hilly sands
24 A	–	Wormwood–psammophyte-bushy (*Calligonum sinuoso-aculeolatum*, *Krascheninnikovia ceratoides*, and *Artemisia arenaria*)	Hill summit	Hilly sands

tatarica) are formed under these conditions and are a unique aspect of the sand desert.

The Amanat Ecological Profile (Piedmont Valley of the Kurshum Ridge)

The Amanat ecological profile was set from the waterline of the Zaisan Lake at an altitude of 390 m to the branches of the Kurshum Ridge at an altitude of 571 m (Fig. 4, Table 3). The profile is 30 km long. It crosses the high lake terrace with a leveled surface; the surface then gradually becomes slightly undulated and then hilly-ridge; higher, it is replaced by inclined plain. The profile ends in the hummock area, which gives way to low mountains.

The vegetation at the beginning of the profile is represented by *Argusia sibirica* groups on the sand beach. The modern waterline is 10 m lower than the bench of the bedrock coast, which indicates a drop in the lake water level. The high lake terrace is mainly occupied by the alternation of *Anabasis salsa* and *Artemisia terrae-albae* communities allocated to the combination of desert solonetzes and gray-brown desert solonetzic soils. The position near the settlement causes a strong disturbance of the soil cover, which is related mainly to grazing.

At the transition to gently sloping, slightly undulated plain, the soil and grass cover remains complex. It is formed in places by three-member complexes of the *Nanophyton erinaceum* and *Anabasis salsa*, *Artemisia terrae-albae*, and *Anabasis truncata* communities in combination with *Haloxylon ammodendron* woodlands on combinations of solonetzic gray-brown desert soils with thin stony gray-brown desert soils. There are also areas with homogenic plant cover: ephemeral-sagebrush (*Artemisia terrae-albae* and *Descurainia sophia*) communities with woodlands formed by *Haloxylon ammodendron* and *Krascheninnikovia ceratoides*.

The plant cover of the hilly-ridge inclined plain is formed by two variants of communities of *Anabasis salsa*: (i) ephemeral-sagebrush with saxaul (*Artemisia terrae-albae*, *Descurainia sophia*, *Lepidium perfoliatum*, and *Haloxylon ammodendron*) and (ii) with annual saltwort (*Climacoptera brachiata*, *Salsola foliosa*, and *Bassia sedoides*). There are also sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) communities with *Anabasis salsa* or with the participation of *Krascheninnik-*

Table 3. Vegetation of the Amanat ecological profile

No	Altitude (m above sea level)	Vegetation	Mesorelief	Soils
1	390	Sporadic *Argusia sibirica*	Sand bank	Lacustrine sands
2	400	*Nanophyton erinaceum* with *Artemisia terrae-albae*	High lake terrace	Poorly formed gray-brown desert
3	403	Combination of *Anabasis salsa* and *Artemisia terrae-albae* communities	High lake terrace	Combination of desert solonetzes with solonetzic, gray-brown desert soils
4	405	Combination of *Artemisia terrae-albae* and *Anabasis salsa* communities	High lake terrace	Combination of solonetzic gray-brown desert soils with desert solonetzes
5	401	Combination of *Anabasis salsa, Artemisia terrae-albae* communities	High lake terrace	Combination of solonetzic gray-brown desert soils with desert solonetzes
6	400	Combination of *Anabasis salsa, Artemisia terrae-albae* communities	High lake terrace	Combination of desert solonetzes with solonetzic, gray-brown desert soils
7	401	*Anabasis salsa* with *Artemisia terrae-albae*	High lake terrace	Solonetzic, gray-brown desert soils
8	398	*Anabasis salsa* with ephemers and annual saltwort (*Lepidium perfoliatum* and *Salsola foliosa*)	High lake terrace	Desert solonetz
9	410	Ephemeral-sagebrush with saxaul forests (*Artemisia terrae-albae*, *Haloxylon ammodendron*, and *Descurainia sophia*)	Gently inclined, slightly undulated plain	Stony, poorly formed, gray-brown desert
10	411	Ephemeral–sagebrush (*Artemisia terrae-albae*, *Lepidium perfoliatum*, and *Goldbachia laevigata*) with *Haloxylon ammodendron* woodlands and *Krascheninnikovia ceratoides*	Gently inclined, slightly undulated plain	Stony, poorly formed, gray-brown desert
11	419	Combination of *Anabasis salsa* with ephemers (*Descurainia sophia* and *Lepidium perfoliatum*) and *Artemisia terrae-albae* communities	Gently inclined, slightly undulated plain	Combination of desert solonetzes with solonetzic, gray-brown desert soils
12	426	Combination of *Anabasis salsa*, *A. truncata*, *Nanophyton erinaceum*, and *Artemisia terrae-albae* communities with *Haloxylon ammodendron* woodlands	Gently inclined, slightly undulated plain	Combination of solonetzic, gray-brown desert soils with stony thin gray-brown desert soils
13	426	Combination of sagebrush (*Artemisia terrae-albae*) and *Anabasis salsa*) communities with ephemers (*Lepidium perfoliatum*)	Gently inclined, slightly undulated plain	Combination of solonetzic gray-brown desert soils with desert solonetzes
14	429	*Anabasis salsa* with sagebrush and ephemers (*Artemisia terrae-albae* and *Descurainia sophia*) with the participation of *Haloxylon ammodendron*	Hilly-ridge plain	Stony, solonetzic, gray-brown desert

Table 3. (Contd.)

No	Altitude (m above sea level)	Vegetation	Mesorelief	Soils
15	415	*Anabasis salsa* with ephemers and saxaul (*Lepidium perfoliatum* and *Haloxylon ammodendron*)	Hilly-ridge plain	Stony, solonetzic, gray-brown desert
16	420	*Anabasis salsa* with sagebrush (*Artemisia terrae-albae* and *A. pauciflora*)	Hilly-ridge plain	Desert solonetz
17	425	*Anabasis salsa* with annual saltworts (*Climacoptera brachiata*, *Salsola foliosa*, and *Bassia sedoides*)	Hilly-ridge plain	Desert solonetz
18	427	Saxaul (*Haloxylon ammodendron*)	Hilly-ridge plain	Solonetzic, gray-brown desert soils
19	438	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) with *Kraschenninnikovia ceratoides*, *Haloxylon ammodendron*, and *Anabasis salsa*	Hilly-ridge plain	Poorly formed, solonetzic gray-brown desert
20	444	*Spiraea hypericifolia* with *Kraschenninnikovia ceratoides*	Depression between ridges	Ordinary meadow-brown
21	454	*Anabasis salsa* with *Haloxylon ammodendron* woodlands	Ridge slope	Stony, solonetzic, gray-brown desert
22	458	*Anabasis salsa* with *Artemisia terrae-albae* and *Kraschenninnikovia ceratoides*	Ridge summit	Normal gray-brown desert
23	462	Sagebrush (*Artemisia terrae-albae*) with *Anabasis salsa* and *Haloxylon ammodendron*	Ridge slope	Stony, solonetzic, gray-brown desert
24	454	Wormwood (*Artemisia terrae-albae*) with thin *Haloxylon ammodendron* forests	Ridge slope	Stony gray-brown desert
25	437	*Anabasis salsa* with sagebrush (*Artemisia terrae-albae* and *A. pauciflora*)	Hilly-ridge plain	Solonetzic brown desert
26	443	*Anabasis salsa*	Hilly-ridge plain	Desert solonetz
27	445	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) with *Descurainia sophia, Kraschenninnikovia ceratoides,* and *Stipa capillata*	Hilly-ridge plain	Solonetzic brown desert
28	451	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) with *Anabasis salsa* and *Kraschenninnikovia ceratoides*	Hilly-ridge plain	Solonetzic brown desert
29	447	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*)	Hilly-ridge plain	Solonetzic brown desert
30	455	Sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) with *Anabasis salsa*	Hilly-ridge plain	Solonetzic brown desert

Table 3. (Contd.)

No	Altitude (m above sea level)	Vegetation	Mesorelief	Soils
31	457	*Anabasis salsa* with sagebrush (*Artemisia terrae-albae* and *A. pauciflora*)	Hilly-ridge plain	Solonetzic brown desert
32	453	Sagebrush (*Artemisia terrae-albae, A. pauciflora, Anabasis salsa*)	Hilly-ridge plain	Solonetzic brown desert
33	450	Sagebrush (*Artemisia terrae-albae, A. pauciflora*)	Hilly-ridge plain	Solonetzic brown desert
34	452	*Anabasis salsa* with *Atriplex cana* and *Tamarix laxa*	Depression between ridges	Meadow-brown solonetzes
35	458	Sagebrush-saltbush (*Atriplex tatarica* and *Artemisia nitrosa*) with *Krascheninnikovia ceratoides* and *Caragana* sp.	Depression between ridges	Solonchakous meadow-brown
36	466	Combination of sagebrush (*Artemisia terrae-albae*) and *Anabasis salsa* and *Nanophyton erinaceum* communities	Hilly-ridge plain	Combination of solonetzic brown desert soils with stony, poorly formed brown desert soils
37	488	*Anabasis salsa* with sagebrush (*Artemisia terrae-albae* and *A. pauciflora*)	Inclined plain	Solonetzic brown desert
38	523	Sagebrush (*Artemisia sublessingiana* and *A. gracilescens*) with *Anabasis salsa* and *Nanophyton erinaceum*	Inclined plain	Stony, poorly formed brown desert
39	541	Combination of *Anabasis salsa-Nanophyton erinaceum* and sagebrush (*Artemisia sublessingiana* and *A. gracilescens*) communities with the participation of *Stipa orientalis* and *S. capillata*	Inclined plain	Combination of stony, poorly formed brown desert soils with stony normal brown desert soils
40	567	Sagebrush (*Artemisia sublessingiana* and *A. gracilescens*)	Inclined plain	Stony, poorly formed piedmont brown desert
41	571	Sagebrush (*Artemisia sublessingiana* and *A. gracilescens*) with *Nanophyton erinaceum*	Hill summit	Stony, poorly formed piedmont brown desert

ovia ceratoides, *Haloxylon ammodendron*, and *Anabasis salsa*. The sagebrush (*Artemisia pauciflora* and *Artemisia terrae-albae*) association develops on solonetzic brown desert soils in combination with *Anabasis salsa* and *Nanophyton erinaceum* on desert solonetzes.

The plant cover of the depressions between ridges is formed by communities of (i) sagebrush (*Artemisia nitrosa*) with the participation of bushes (*Tamarix laxa*, *Caragana frutex*, and *Spiraea hypericifolia*); (ii) *Anabasis salsa* and *Atriplex cana* with participation of tamarisk (*Tamarix laxa*); and (iii) *Spiraea hypericifolia* with *Krascheninnikovia ceratoides*.

Woodlands formed by *Haloxylon ammodendron* are mainly developed on the ridge slopes. Saxaul occupies usually 5–7% of the area on a background of sagebrush (*Artemisia pauciflora* and *Artemisia terrae-albae*) and *Anabasis salsa* communities. In some places on the slopes at altitudes of 410–454 m above sea level, the projective cover of saxaul may rise up to 15%.

Near the low mountains of the Kurshum Ridge, *Nanophyton erinaceum* allocated to poorly formed stony brown desert soils becomes a landscape-forming plant.

Rare plant communities revealed in the eastern part of the Zaisan Depression are formed by saxaul

(*Haloxylon ammodendron*), sea buckthorn (*Hyppophae rhamnoides*), thick trefoil (*Hedysarum scoparium*), turanga (*Populus diversifolia*), and *Calligonum* species endemic to the Zaisan Depression (*C. sinuoso-aculeolatum*, *C. dissectum*, *C. pappii*, and others). There are also associations with the participation of groups of *Caragana tragacanthoides*. The rare communities are unevenly distributed in the area. The *Populus diversifolia*, *Hyppophae rhamnoides*, *Calligonum*, and *Hedysarum scoparium* groups occur in the Black Irtysh sands. Some of the rare communities develop in hard-to-access areas: *Hedysarum scoparium* is located in depressions in the high-ridge barkhan sands at the boundary with China. This plant does not occur beyond the Zaisan Depression, and monitoring of all of its communities is required. Woodlands of *Haloxylon ammodendron* developed on the hilly-ridge plain in the northeastern part of the depression, lacustrine-alluvial plain, and slopes of residual hills. An analysis of retrospective data shows that their areas have become considerably smaller. We revealed only saxaul bushes, and the absence of trees is a troubling sign. Groups of rare endemic *Caragana tragacanthoides* were seldom described on the stony slopes of the Ashutas, Kara-Biryuk, Kiin-Kerish, and Shekel'mes residual mountains.

CONCLUSIONS

The research has shown that the spatial regularities of the plant cover in the eastern part of the Zaisan Depression are determined by a combination of ecological factors. On the piedmont plains of the Kurshum and Manrak Ridges, the development of plant communities is related to the altitude above sea level, mesofeatures of the topography, the stone content in soils, the formation rate of the soil cover, and the salinity of soil-forming rocks. The altitude determines the inversion zonality of the soil and plant cover. The central lowland part of the depression is characterized by the driest conditions. From the north, the depression is bordered by the belt of gray-brown desert soils with combinations of *Artemisia terrae-albae* communities on gray-brown desert soils and *Anabasis salsa* communities on desert solonetzes. The belt of brown desert soils begins at the altitude of 437 m in the northern part of the depression and of 399 m in its southern part. The solonetzic brown desert soils are occupied by sagebrush (*Artemisia terrae-albae* and *A. pauciflora*) communities, often in combination with *Anabasis salsa* and *Nanophyton erinaceum*. The nonuniformity of the plant cover is also determined by the development of run-off depressions and the shallow level of saline groundwater.

The bank of the Zaisan Lake is low in the southern part and elevated in the north, which results in the development of different plant communities. The northern part of the bank is occupied by sand beaches with thin groups of *Argusia sibirica*. On the southern part of the bank, the well-pronounced low lake terrace is occupied by intrazonal vegetation represented by *Phragmites australis*, *Typha laxmannii*, *Rumex aquatica*, *Glycyrrhiza uralensis*, *Leymus angustus*, and *Achnatherum splendens*.

The plant cover pattern in the Black Irtysh sands depends on the topography of the massif, the age and blow rate of sands, the salinization of sand soils in depressions between ridges, and the groundwater depth and salinity.

We have revealed rare plant communities of the Zaisan Depression formed by saxaul (*Haloxylon ammodendron*), sea buckthorn (*Hyppophae rhamnoides*), thick trefoil (*Hedysarum scoparium*), turanga (*Populus diversifolia*), and *Calligonum* species endemic to the Zaisan Depression (*C. sinuoso-aculeolatum*, *C. dissectum*, *C. pappii*, and others). There are also communities with the participation of groups of *Caragana tragacanthoides*. The monitoring and mapping of unique communities, as well as education of the local population, are necessary for their preservation.

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