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SYSTEMATIC STUDY OF ARID TERRITORIES

Regional Features of Desertification Processes of Ecosystems on the Border of the Baikal Basin and Central Asian Internal Drainage Basin

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Abstract—The article describes the regional features of ecosystem desertification in the southern periphery of the Baikal basin that are located in the zone of cross-border interaction between the southern Siberian and the Central Asian internal drainage basin landscapes. The nature of such interactions is identified as invasive, which is associated with the penetration of desert-steppe plant species: *Caragana bungei* are found in larch forests, and *Allium polyrrhizum* are found in dry steppes. A high degree of species adaptation to the modern arid climate is defined by ecological and physiological analysis of these species characteristics. The significant predominance of *Caragana bungei* and *Allium polyrrhizum* in the current structure of plant communities makes it possible to identify a long-term and widespread invasive succession and to characterize this process as a specific desertification form.

Keywords: desertification, aridization, *Caragana bungei*, *Allium polyrrhizum*, invasive succession, steppe, dry steppe, Baikal basin, Central Asian internal drainage basin

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INTRODUCTION

The current ecosystems of the Baikal basin are exposed to strong changes under the influence of anthropogenic and natural factors, and these changes are repeatedly described in the literature (Miklyaeva et al., 2004; *Ekosistemy*..., 2005; Bazha et al., 2012). The zone of high risk is in this case the southern periphery of the Baikal region, which represents the ecotone between the boreal ecosystems of southern Siberia and the arid ecosystems of the Central Asian internal drainage basin. The research conducted on these ecosystems in recent years make it possible to speak about the cross-border interaction between the landscapes of these regions, causing degradation in the vegetable cover (Gunin et al., 2012, 2014a, 2014b). The character of degradation processes can be identified as digression-invasive, which is primarily associated with penetration into the steppe and forest-steppe landscapes of desert-steppe plant species. Thus, it should be noted that the proceeding invasive successions in the western and southern parts of the Baikal basin differ with respect to both the dominant species that actively participate in them and their territorial coverage and landscape confinedness.

The history of digressive processes in the steppes at the western edge of the Baikal basin is in many ways caused by the soil covering features—the significant distribution of sand massifs, as well as the latitudinal direction of main wind streams, which carry and redeposit sand blown from the Great Lakes Depression. A

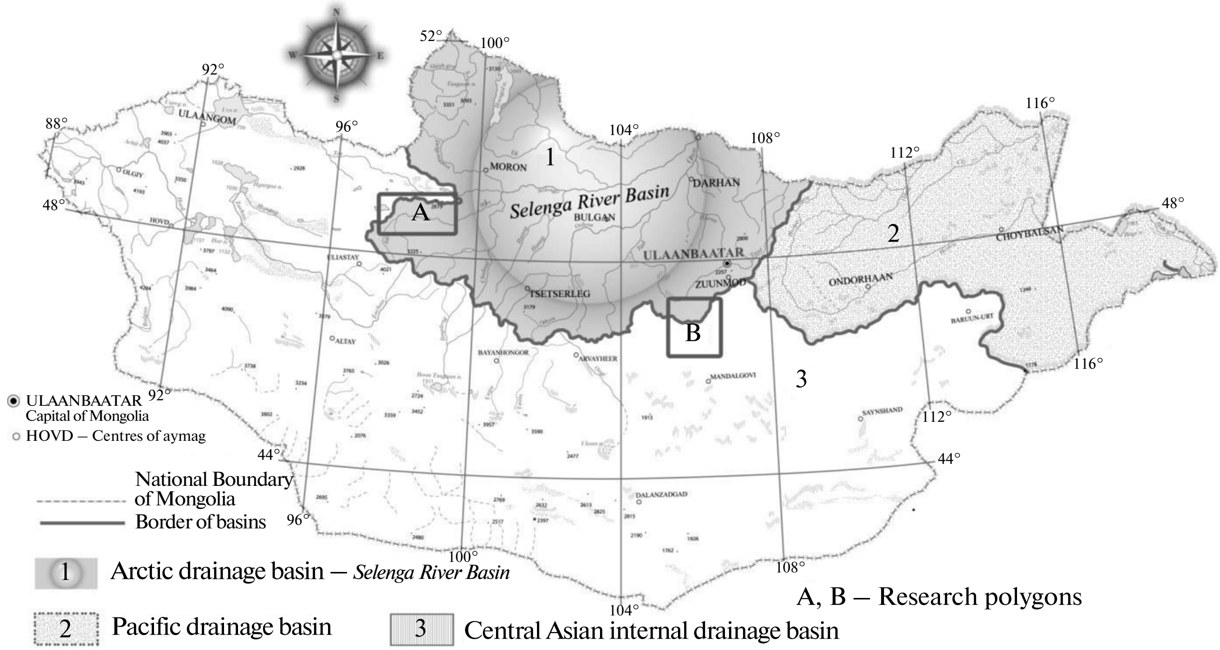

Fig. 1. Location of research polygons in the transboundary zone of the Baikal basin and the Central Asian internal drainage basin.

widespread tendency that deserves serious attention is the change in the species composition of the vegetable cover, which is caused by the total effect of major destructive processes: eolian and pasture degradations. One result of this is the distribution of a psammophilous desert-steppe Bungei pea shrub (*Caragana bungei*), which leads to the formation of a unique type of forest plant communities in which the tree layer is represented by the taiga species (*Larix sibirica*) and the shrub is represented by the desert-steppe (*Caragana bungei*).

In the southern part of the Baikal basin, the implementation of a desert-steppe plant species—multirooted onion (*Allium polyrrhizum*)—and the formation of extrazonal monodominant plant communities of this species take place in the communities, which are intensively used for stocking the dry steppe plant communities with reduced phytocoenotic indices and a low participation of indigenous cenosis formers—sod grasses of *Agropyron cristatum*, *Koeleria cristata*, and *Stipa krylovii.*

The ecological and physiological features of the above species allow us to diagnose these processes as desertification. In this regard, it is of scientific and practical interest to study the course and direction in the processes of this desertification form and their regional features; the identification of the anthropogenic and natural factors causing the penetration and expansion of the area of desert-steppe plant species in the Baikal region (*Caragana bungei* in the larch forests and *Allium polyrrhizum* in the zonal dry steppe plant communities), as well as the physiological mechanisms that provide them a competitive advantage over native species.

MATERIALS AND METHODS

The research was conducted in the Mongolian part of the Baikal basin in 2004–2014. The *Caragana bungei* invasions in the forest-steppe ecosystems have been studied in the territory of the Tosontsengel and Ikh-uul sums in a middle part of the Ider River basin on the east of the Zavkhan aimag (Fig. 1; Table 1). The climate is characterized by very severe winters and subhumid summers. The long-time average annual temperature is –32.4°C in January and 14.5°C in July. The long-term average yearly precipitation is 230 mm, most of which falls in July. According to Lavrenko (1991), the considered territory belongs to the Western Khangai mountain-forest steppe subprovince, which is characterized by alternating massifs of larch forests with mountain steppes. It is included in the Khangai-Daur province of the Central Asian steppe subregion. The larch forests, which are composed of *Larix sibirica*, are presented here by two main variants. The valley forb-grass forests grow on the sand alluvial sediments of the Ider River and its tributaries at a height of 1640–1740 m with a density of 0.3–0.4 or lower. The underbrush is represented in them by the prairieweed (Potentilla fruticosa). *Poa sibirica*, *Agrostis trinii*, *Agropyron repens*, *Achillea millefolium*, *Carex amgunensis*, *Sanguisorba officinalis*, and others are the most abundant in an herbaceous cover. The closed (0.5–1.0) mountain forests occupy the northern mountain slopes with actual elevations of 1800–2070 m. The underbrush is sparse and is represented by honeysuckle (*Lonicera altaica*), ipecac (*Spiraea media*), barberry (*Berberis sibirica*), cotoneaster (*Cotoneaster melanocarpa*), and prickly wild rose (*Rosa acicularis*). The

Table 1. Plant communities studied in the transboundary zone of the Baikal basin and Central Asian internal drainage basin

Index	Association names	Coordinates	Absolute height, m
54-1	Forb-grass-sedge-pea larch forest	N 48°42′35.0″ E 98°38′51.8″	1814
54-2	Forb-grass-pea with a single larch	N 48°42′37.0″ E 98°38′50.6″	1815
54-3	Forb-cold wormwood-grass-pea	N 48°42′37.38″ E 98°38′53.91″	1785
55-1	Petrophytous forb-junegrass with pea shrub	N 48°43′42.3″ E 98°22′20.4″	1713
56-1	Sedge-forb larch forest with pea shrub	N 48°39′01.7″ E 98°56′01.4″	1858
56-2	Petrophytous forb-grass-sedge-pea with a single larch	N 48°39′02.1″ E 98°56′08.1″	1875
56-3	Grass-sedge-forb-pea steppe meadow with a single larch	N 48°39′02.3″ E 98°56′10.2″	1856
56-4	Sedge-grass-petrophytous forb-pea	N 48°39′13.5″ E 98°56′07.3″	1870
58-3	Forb-wormwood-grass-shrub	N 48°44′59.2″ E 98°02′37.3″	1866
58-4	Forb-cold wormwood-cinquefoil-grass with pea shrub	N 48°44′55.7″ E 98°02′38.7″	1832
58-5	Thyme-grass-pea	N 48°43′50.4″ E 98°02′38.7″	1740
25	Onion-ephedra with an annual synusium	N 47°07′59.1″ E 106°04′29.8″	1236
MG-X	Onion	N 46°08′33.5″ E 106°30′51.4″	1362
MG-X-1	Onion	N 46°08′33.9″ E 106°30′47.7″	1366
MG-X-2	Onion	N 46°08′28.4″ E 106°32′32.6″	1352
MG-X-3	Onion	N 46°08′28.2″ E 106°32′52.8″	1334
MG-X-4	Onion	N 46°08′28.0″ E 106°32′50.9″	1332
DTS-3	*Allium polyrrhizum-Reaumuria songarica-Salsola passerine* with annuals	N 46°10′43.6″ E 106°31′39.3″	1316

forest-meadow (*Lathyrus humilis, Thalictrum minus, Galium boreale, Geranium pseudosibiricum, Poa sibirica* and others) and forest-steppe (*Bromus pumpelliana, Aconitum barbatum, Carex amgunensis, Carex pediformis, Galium verum* and others) species are represented in the herbaceous cover (Dorzhsuren, 2009). The lower part of gentle hill slopes and the level surface adjoining them are occupied by low-bunchgrass dry and mesoxerophytic steppes on chestnut soils. The mountainous slopes are occupied by petrophytous forb low-bunchgrass steppes with pea shrubs and a larch.?

The onion plant communities from *Allium polyrrhizum* were studied in the Bayan-Undzhul sum of the Tuv aimag and the Delgertsogt sum of the Dundgovi aimag (Fig. 1, Table 1). The average temperature of January is –17.7°C and 19.3°C in July at the meteorological station that is nearest to this sum in Mandalgovi. The average annual precipitation is 156 mm, the maximum of which is in July–August. The studied territory is located in the subzone of dry bunchgrass steppes of the Middle Khalkha subprovince of the Mongolian province in the Eurasian steppes (Lavrenko, 1991). The low-bunchgrass-stipa and stipa-pea plant communities from the sod grasses of *Stipa krylovii, Agropyron cristatum, Cleistogenes squarrosa, Koeleria cristata*, with onions *Allium anisopodium, A. bidentatum, and A. teniussimum* on chestnut soils were previously the most widespread here (The vegetation map of the Mongolian People's Republic, 1979).

Field studies were conducted during the height of herbage (the mid-July—the mid-August). We used in the paper methods of the qualitative and quantitative assessment of ecosystems by the nature of the vegetable cover; the methods were described in detail earlier (Gunin et al., 2010; 2012; Bazha et al., 2012; Bazha et al., 2013). Biomorphometric indices were studied, including the height and diameter of the crown in the partial bushes of *Caragana bungei* and heights, the number of vegetative and reproductive shoots, and the diameter of sods in *Allium polyrrhizum*.

To assess the developmental character of the *Caragana bungei* bush in larch forests with various densities, we used the growth tension, which is defined as the ratio of height to diameter and serves as the physiological and morphological state reflection of both an individual tree and forest stand in general. It was developed for the first time by Medvedev (1884) and specified later by Vysotskii (1962).

The invasiveness coefficient was used to determine the development rate of invasive processes in dry steppe ecosystems, which is shown as the ratio of the biomass of the introduced and indigenous species and was proposed by us for the first time in 2008 (Bazha et al., 2008).

The ecological and geobotanical studies included the ecological and physiological monitoring of basic parameters of photosynthesis and water exchange in the invasive species, as well as the diurnal dynamics of gas exchange with an evaluation of carbon and water exchange stability with respect to the environmental conditions. The studies of morphological and physiological features of *Caragana bungei* were carried out under the conditions of a flat petrophytous forb-junegrass steppe with pea shrub (55-1) and on an environmental profile including mountain petrophytous steppe (54-3), a steppe plant community on the edge of the larch forest (54-2), and larch forest (54-1). The research on *Allium polyrrhizum* was conducted on the onion plant community (MG-X) (Table 1). The intensity of gas exchange was measured with a Li-6400x portable photosynthesis system (Li-Cor, United States) at 24°C in the chamber and at a light intensity of 1500 μmol of photons/(m^2 s). In the onion plant communities, the life state of resting sod grasses of *Stipa krylovii* and *Cleistogenes squarrosa*, and *Allium polyrrhizum* was assessed based on anatomical research by the methods of Enikeev et al. (1995) and Barykina et al. (2005).

RESULTS AND DISCUSSION

***Caragana bungei* Ledeb.** is a psammophilous desert-steppe. Multibranched shrub up to 2.5 m high with the Altai-Sayan-West-Mongolian plant growth habit that is mainly distributed in piedmont trains and plains of the desert steppes, on stony-rubble slopes, and on sand (Grubov, 1982; Gubanov, 1996). The shrub feather-grass and cleistogenes-feather-grass steppes with dominant *Caragana bungei* are the landscape-forming vegetation type in the Great Lakes Depression in the desertificated and desert steppes (Lavrenko, 1991).

In 2004, we found on the western periphery of the Baikal basin that *Caragana bungei* defines the structure of degraded steppe plant communities along the lower part of gentle hill slopes and the adjacent level surface, with actual elevations of 1700–1900 m (55-1, 58-4, and 58-5 sections). The grasses *Agropyron cristata, Koeleria macrantha, Stipa krylovii* dominate here in the herbaceous layer. A prominent role in the communities is played by *Artemisia frigid* and *Potentilla acaulis*. *Arenaria capillaris, Artemisia commutata, Potentilla bifurca, Bupleurum bicaule*, and *Caragana stenophylla* are the constant species. *Caragana bungei* forms from 11 to 34% of the total projective cover in the structure of these communities (Table 2).

Caragana bungei penetrates into the communities of petrophytous mountain steppes and meadow-steppe and meadow plant communities on the edges by the sand deposits, which are formed as the result of aeolian transfer. The participation of this shrub varies greatly in the petrophytous steppes on mountain slopes. Twenty-three specimens of *Caragana bungei* are noted in the forb-wormwood-grass shrub mountain steppe (58-3) on a scarp rocky slope of a southeastern exposition per 100 m^2; however, their projective cover was only 6%. The abundance and participation of *Caragana bungei* significantly increase in the petrophytous-sedge-grass-forb-pea plant community (56-4) with thinned vegetation, where it is 55% of the total projective cover. Sixteen specimens were noted per 100 m^2, and the projective cover is 16%. At the edges the share of projective cover of pea shrub is 32–53%. A significant share (more than 50%) of *Caragana bungei* in the structure of projective cover is noted in the petrophytous forb-grass-sedge-pea plant community (56-2). Here, its number reaches 29 individuals per 100 m^2, and the projective cover is more than 26% (Table 2).

The redeposited ancient aeolian sand deposits on the fairly steep (20°–30°) mountain slopes of the northeastern exposure serve as natural conserved corridors for the penetration of *Caragana bungei* into communities of larch forests on the mountain slopes. *Caragana bungei* forms more than 30% of the total

Table 2. Projective cover (%) of the major species* in the plant communities with *Caragana bungei* in the Zavkhan aimag (Tosontsengel and Ikh-uul sums, 2004 and 2014)

Life form, species	54-1		54-2		54-3	55-1		56-1		56-2		56-3	56-4	58-3		58-4		58-5	
	2004	2014	2004	2014	2014	2004	2014	2004	2014	2004	2014	2004	2004	2004	2014	2004	2014	2004	2014
Trees																			
*Larix sibirica***	0.2–0.5	0.5	–	3 pcs.				0.4–0.6	0.5–0.6		4 pcs.	3 pcs.							
Shrubs																			
Amygdalus pedunculata				8	2														
Berberis sibirica														5	2				
Caragana bungei	12.4	28.3	11.6	28.1	8	5	3.6	3	4.5	26.3	26.6	19	16.1	5.9	7.9	6.8	6.9	26.0	2.6
C. stenophylla					8	0.1				0.1			0.1		1	0.3	0.5		0.2
Cotoneaster melanocarpa	1	3		1				0.1		1		0.2		2					
Lonicera altaica		1												2					
Potentilla fruticosa	0.1	1	1	8					4	0.5	3	0.1		1	1				
Spiraea flexuosa														2					
S. hypericifolia	3	6.5	0.5	7						1	0.2	0.1	0.1						
S. media								0.1	1.5						0.5				
Dwarf semishrubs																			
Artemisia frigida			1	1	5	1	0.3			2	0.3		0.1	1	3	8	2	1	
A. rutifolia													1	7	1				
Kochia prostrata			1										0.1					1	0.2
Thymus gobicus						1	0.2											18	
Perennial grasses: cereals																			
Agropyron cristatum			3	5	10	3				3	0.5	0.1	3	10	2.5	10	2	12	2
Agrostis trinii									2		5								
Bromopsis inermis	1	3																	
Elymus sibiricus									10			0.1							
Festuca lenensis	1		2				4			1				1	1		0.3		4

Table 2. (Contd.)

Life form, species	54-1		54-2		54-3	55-1		56-1		56-2		56-3	56-4	58-3		58-4		58-5	
	2004	2014	2004	2014	2014	2004	2014	2004	2014	2004	2014	2004	2004	2004	2014	2004	2014	2004	2014
F. sibirica									6		2								0.2
Helictotrichon schellianum	3																		
Koeleria macrantha			1	2	5	10	3			1		2		2	1.5	5	3	3	6
Poa attenuata												1		2	1				
P. sibirica		4		0.1					1.5						0.5				
Stipa krylovii			5	4	10	2	2			1			1	10	2	10	4	5	5
sedges																			
Carex duriuscula				4			1										1.5		2
C. korshinskyi				1														4	
C. pediformis	10	10	0.1					5	10	5	25	5	0.1	0.1	0.5				
forbs																			
Androsace septentrionalis	0.1					0.1		0.1		0.1		0.1							0.2
Arenaria capillaris						0.5	1.5							0.5		1	0.2		3
Artemisia dracunculus			3	0.1														0.1	
Aster alpinus	0.1			0.1				1	0.5		0.5	2	0.1					0.1	
Bupleurum multinerve								5											
Carum carvi		0.1	0.1							0.1		0.1	0.1					0.1	
Dianthus versicolor			0.1	1						0.1		0.1					0.1		
Draba nemorosa								0.1	1.5	0.1	1.5	1							
Dracocephalum foetidum													1	2					
Erodium stephanianum			1										2						

Table 2. (Contd.)

Life form, species	54-1		54-2		54-3	55-1		56-1		56-2		56-3	56-4	58-3		58-4		58-5	
	2004	2014	2004	2014	2014	2004	2014	2004	2014	2004	2014	2004	2004	2004	2014	2004	2014	2004	2014
Galium verum	2	3						2	3	0.1	2	2						1	
Heteroppapus altaicus			0.1	1	3		0.5				0.1					0.1			0.2
Krascheninnikowia ceratoides										3									
Lappula intermedia			0.1							2		1							
Linaria acutiloba		2	0.1	0.1				0.1		0.1					0.3				
Panzeria lanata			0.1			0.1							0.1	0.1	3.5		1		
Phlomoides tuberosa	0.1	3		0.1															
Potentilla acaulis			1	3	0.1	1	9				0.3			1	7	12	6	1	12
Thalictrum minus	2	10		1	3	0.1		3	1	0.1	10	1	0.1		1				
Veronica incana			1	0.1		1	2		0.5	0.1	0.5	1							4
Vicia megalotropis								2	0.3										
Annual-, biennial grasses:																			
Artemisia palustris						2							1						
Dontostemon integrifolius			1	0.1										2		0.1			
Erysimum cheiranthoides								15	0.5			3							
Total	39.4	75.3	35.7	77.8	54.7	27.9	30.1	38.3	48.3	49.3	79.4	41.6	29.2	62.4	39.4	59.6	30.7	76.8	44.1
Number of species per 100 m^2	23	18	27	33	16	20	20	22	18	28	21	28	30	37	24	19	20	22	21

* There are no species with a projective cover of 1% or less; ** the normality or their number is indicated in the plant communities at forest edges.

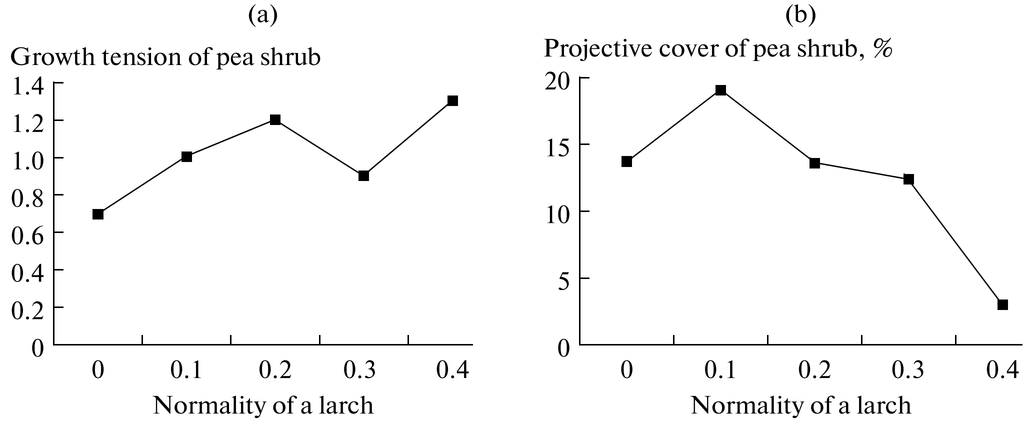

Fig. 2. Dependance of growth tension (a) and projective cover of *Caragana bungei* (b) on the density of *Larix sibirica*.

cover of shrub-herbaceous cover in the thinned larch forests on the mountain slopes (the density is 0.2–0.5), e.g., as in the forb-grass-sedge pea forest (54-1), while the participation of forest shrub species (*Cotoneaster melanocarpa, Potentilla fruticosa, Rosa acicularis* and *Spiraea hypericifolia*) is only 10%. The number of *Caragana bungei* is 16 specimens per 100 m^2 on the average, and the projective cover is over 12%. The abundance of *Caragana bungei* is reduced inlarch forests with a higher density than that of the forest stand (0.4–0.6). Thus, its number in the sedge-forb larch forest with pea shrub (56-1) was 12 specimens per 100 m^2, and the projective cover was 3%. Other shrubs (*Cotoneaster melanocarpa* and *Spiraea media*) occur singly here (Table 2).

The repeated study, which was conducted 10 years later in 2014, revealed a progressive degradation of vegetation in the steppe plains and the lower parts of hills, which is expressed in the reduction of the projective cover of grasses in all communities and in the increased participation of digressive-active species (*Potentilla acaulis, Veronica incana*, etc.). There is the constant abundance of Caragana bungei in the forb-cold wormwood-cinquefoil-grass plant community with pea shrub (58-4), and its participation in the structure of this community has increased twice due to a reduction of the projective cover of practically all of the keystone species composing it. A decrease in the projective cover and the coenotic role of *Caragana bungei* was noted in the petrophytous forb-junegrass plant community with pea shrub (55-1) and in the thyme-grass-pea plant community (58-5) (Table 2). According to our observations, this is connected to the intensive use of this area for pasture and to the proximity of the Ider floodplain, where the camps of Mongolian cattle breeders and their cattle concentrate in the summer, as well as to the cuttings of pea shrubs by the indigenous population for fuel. The considerable increase in the abundance of *Potentilla acaulis* as the main vegetable indicator of pasture digression in Transbaikalia reflects the high pasture loads (Gorshkova et al., 1977).

A decrease in species diversity and total projective cover was noted in a mountain forb- wormwood-grass-shrub steppe (58-3). At the same time, the projective cover and the participation in the structure of the Caragana bungei plant community increased. The abundance of other shrubs, the dwarf subshrub of *Artemisia rutifolia*, and grasses decreased. The participation of digressive-active species of *Artemisia frigida, Potentilla acaulis*, and *Panzeria lanata* increased. The abundance of pea shrub increased on the edges in the forb-grass-pea plant community (54-2). However, the participation in the community structure of this shrub practically did not change as compared to 2004 due to an increase in the total values of projective cover. The projective cover also increased in other species of shrubs, sedges of *Carex pediformis*, and grasses of *Agropyron cristatum, Koeleria macrantha*. In the petrophytous forb-grass-sedge-pea plant community (56-2) the abundance of pea shrub did not change. However, an increase in the total projective cover that was due to the overgrowth of *Thalictrum minus* and *Carex pediformis* was noted (Table 2).

The most expressed positive dynamics of the abundance of *Caragana bungei* was noted in the mountain larch forests. Thus, its projective cover increased in the thinned larch forest by 2.3 times (54-1). In the community structure, this species forms more than 37% of the total projective cover. The abundance also increased in other shrub species. The presence of *Thalictrum minus* increased significantly. The projective cover of pea shrub increased by 1.5 times in the closed larch forest (56-1). Its participation in the community structure also shows the positive dynamics. At the same time, there was an increase in the abundance of shrubs, grasses, and sedges, which allowed the total projective cover to increase by 1.3 times. At the present time, the dominants are *Elymus sibiricus* and *Carex pediformis* (Table 2).

The analysis of the growth tension of *Caragana bungei* in the larch forests showed that its crowns had a more or less distinct tendency to acquire an elongated cylindrical shape with an increasing forest stand density, i.e. the growth tension increased (Fig. 2). In addition, the study of shoot architecture showed that the branching index (number of branches per meter in the length of a shoot) decreased for steppe areas (9.2 m^{-1}), the forest edge (6.6 m^{-1}), and the larch forest (5.3 m^{-1}). The decrease in branching intensity is an important adaptive feature of shrubs in forest ecosystems; it is connected to the competition for the direct light. This species of pea shrub is not adapted to growing under the forest canopy, so its response to shading is different from the response of forest shrubs. It is believed that *Caragana bungei* responds to the competition from larch for the light, just as to intraspecific competition, i.e. it accelerates height growth due to the weakened lateral growth.

A feature of *Caragana bungei* is its higher rate of photosynthesis in the leaves as compared with the other shrub species growing in this area. The high photosynthetic ability is explained, on the one hand, by its assignment to the legume family, in which symbiosis with nitrogen-fixing organisms provides more effective nitrogenous nutrition, and, on the other hand, by the fact that the pea shrub leaves have a powerful photosynthetic apparatus that is characterized by a high concentration of photosynthetic cells (up to 3 million/cm^2) and chloroplasts (up to 30 million/cm^2) in the unit area of a leaf. The maximum values of photosynthesis for this species are noted under the conditions of the flat steppe (55-1), where the sizes and biomass of separate individuals of pea shrub were also the highest (Fig. 3). In addition, the maximum level of transpiration losses during the day was also noted in these conditions (Fig. 3), which indicates a good condition of the water supply of shrubs in this ecotope. Under the conditions of a mountain slope, on the contrary, a significantly lower level of gas exchange of *Caragana bungei* was revealed. The transpiration rate in leaves was 4–6 times lower, which indicates unfavorable moisture conditions on a mountain slope. The received physiological data are confirmed also by the parameters of the leaf structure, which are formed during the whole growing season of leaves and reflect the long-term adaptation of photosynthesis to the environment conditions. The density and thickness of a pea shrub leaf under the conditions of a mountain slope are lower than in the flat steppe (Fig. 3). Since the density and thickness of a leaf have a high positive correlation with the maximum rate of photosynthesis in this species (coefficient $r = 0.71$, $p < 0.001$ and $r = 0.87$, $p < 0.001$, respectively) according to our data, the results indicate a reduction of the assimilatory ability in pea leaves under the conditions of a mountain slope. With a reduction of the photosynthetic activity per unit area of a leaf, it is necessary to increase the share of leaves in the plant mass, which was found in the pea shrub. Under the conditions of a mountain slope, the share of leaves in the above-ground mass of a shrub was 10–14%, as compared with the 7% share of leaves for pea shrub on the plain (55-1).

The analysis of physiological parameters of pea shrubs on the "steppe—edge—forest" profile showed that, on the steppe areas of the mountain slope, the pea shrub has the high water use efficiency (WUE and the amount of absorbed carbon dioxide per unit of transpiration water), which directly indicates a moisture deficit and a need for a considerable saving of resources under these conditions. WUE in the shrubs decreases with advancement in the larch forest, reaching the values that are typical for pea shrub on the plain. This, in turn, indicates a favorable water regime for the species, which was noted for other shrub species earlier (Ivanova et al., 2012). At the same time, shading from the forest canopy does not allow the development of high photosynthetic productivity. Within the ecological profile on a mountain slope in the direction from the steppe areas to the forest, the density and thickness of a leaf, as well as the rate of photosynthesis, is reduced due to a lack of lighting. However, experiments with a different level of lighting showed that the forest and edge pea shrubs can reach almost the same rate of photosynthesis with high lighting, as well as in the steppe slope. This means that the powerful photosynthetic apparatus of the pea leaves is able to provide a stable positive carbon balance and steady growth in the thinned forest, where sunspots can give high light for extended periods of time.

Climatic factors, along with the anthropogenic and geomorphic, also belong to the main prerequisites for the emergence and distribution of degradation processes of forest-steppe landscapes in the western boundary of the Baikal basin.

Analysis of the climatic data from the Tosontsengel weather station since 1961 shows that 1992 had the maximum wetness (443.6 mm) and 1978 had the most drought (147.3 mm). If we consider five-year cycles over the past 50 years, the amount of precipitations decreased in 1966–1980 (185–210 mm) and 1996–2005 (189–209 mm). The wet periods were 1961–1965 and 1991–1995, when the amount of precipitation exceeded the long-time average annual value and was 264–313 mm (Fig. 4a). If we analyze the dynamics of the annual amount of precipitations for 1994–2014, a predominance of periods with moistening below the long-time average annual value can be seen. There were six periods with a duration of one to four years, and the frequency ranged from one to two years. The period 1999–2002 was the longest drought period. As regards the dynamics of yearly average air temperature, 1998 is considered the warmest (–3.7°C) and 1981 is the coldest (–8.0°C). We will consider the dynamics of average temperatures during the growing period (May–September) for the five-year cycles. The long-time average annual value of this indicator is 10.6°C. Until the mid-1990s, this temperature ranged

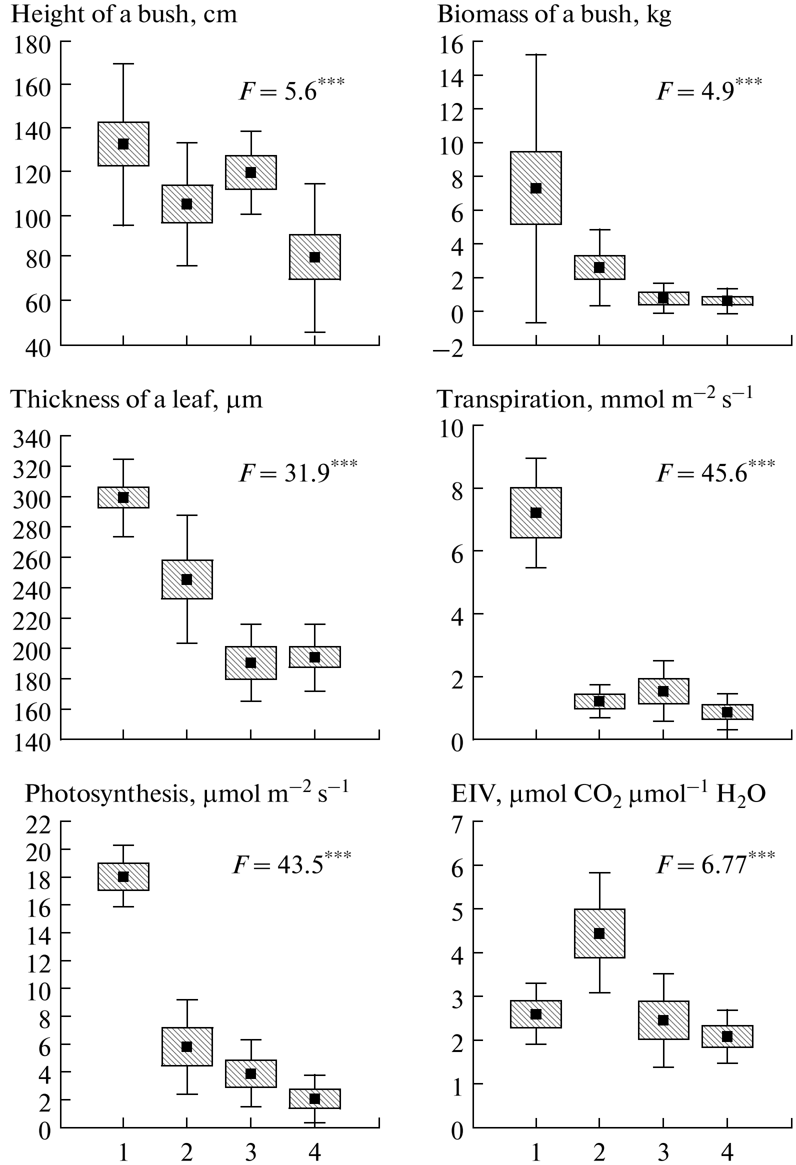

Fig. 3. Morphological and physiological characteristics of *Caragana bungei*: (1) flat steppe (55-1) and on the ecological profile, (2) mountain petrophytous steppe (54-3), (3) edge of larch forest (54-2), and (4) larch forest (54-1). The point on the chart is the mean, the rectangle is error of the mean, and the end point is the standard deviation. Fisher criterion *F*. Reliability: *** indicates $p < 0.001$.

within 9.9–10.4°C. In the following period, it increased to 11.1–11.6°C (Fig. 4b). In the last 21 years, the growing period was the coldest in 1994–1996. From 1997 to the present, the average temperatures in practically all vegetation cycles exceeded the long-time average annual value, thereby favoring the development of such species as *Caragana bungei*.

The arid climate, which was identified based on the analysis of the dynamics of climatic indices, in all probability, leads to the formation of favorable conditions for pea underbrush in thinned larch forests. The most favorable conditions for its development are revealed in the thinned larch forest and on an edge, in which the maximum projective cover of *Caragana bungei* was determined in 2014 (Table 2).

The latitudinal valley stretch of the Ider River and prevailing wind streams, which coincide with it and carry sand and desert plants seeds, are also significant factors in the distribution of pea plant communities. Thus, according to the meteorological observations, the number of days in a year with dust storms exceeds 30 in areas of the West Khangai, and the number of days with wind speed over 15 m/s also reaches an average of 30 days per year. As a result of these processes, ecotypes suitable for the settlement of pea shrub are formed.

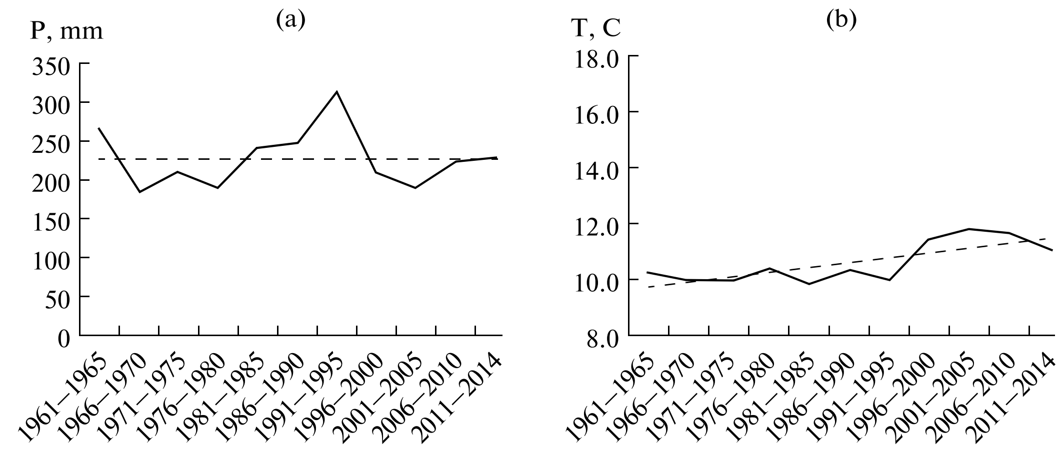

Fig. 4. Dynamics of the average five-year annual precipitation values (a) and the average temperature during the vegetative period (May–September) (b) at the Tosontsengel weather station.

Thus, the distribution of *Caragana bungei* to communities of the hemiboreal larch forests in the taiga-meadow-steppe belt of the mountains is promoted by the peculiar conserved corridors, which formed as a result of aeolian transfer, as well as the insignificant presence of competition in the shrub cover.

***Allium polyrrhizum* Turcz. ex Regel** is a firm-bunch perennial ombrophyte characterized by the succulence of assimilatory shoots that belongs to the desert-steppe ecological-coenotic type with the Junggar Mongolian plant growth habitat (Bobrovskaya and Nikulina, 2013). *Allium polyrhizum* plays the role of an edificator or coedificator in the peculiar *Stipa glareosa-Allium polyrrhizum, Allium polyrrhizum-Stipa glareosa, Anabasis brevifolia-Allium polyrrhizum-Stipa glareosa, Stipa glareosa-Allium polyrrhizum-Anabasis brevifolia*, and other Central Asian desert-steppe plant communities. It is most common in the East Gobi, the Gobi lake valley, and Gobi Altai, and it penetrates to the west into the southern part of the Great Lakes Depression (Kalinina, 1954, 1974; Umarov and Yakunin, 1974; Yunatov, 1954, 1974; Evstifeev and Rachkovskaya, 1977). *Allium polyrrhizum* was not noted earlier in the zonal plant communities of dry steppes, and it penetrates only in the form of a small impurity of the cleistogenes-stipa and cleistogenes steppes on the extrazonal alkaline-saline depressions (*Karta rastitel'nosti...*, 1979; *Kormobotanicheskaya karta...*, 1981; *Sukhie stepi...*, 1984).

For the first time, the introduction of *Allium polyrrhizum* in the zonal dry steppe plant communities were revealed in 2008 in the territory of the Bayan-Undzhul sum in the intermountain Sharkhan-Hundey valley (section 25) (Table 1). In the onion-efedra plant community with annuals, the dominant is another invasive species in dry steppes—the *Ephedra sinica* dwarf subshrub, which was in detail considered earlier in the article by Gunin et al. (2012). The codominant of *Allium polyrrhizum* forms more than 16% of the total above-ground mass (Table 3).

The research conducted by us in 2009 showed that the monodominant onion plant community formed on a considerable part of the Middle Gobi aimag in the subzone of dry steppes. More than 80% of the total above-ground biomass in its structure is *Allium polyrrhizum*. This process occurs against the oppression of indigenous species in these steppes—grasses of *Stipa krylovii, Koeleria cristata, Agropyron cristatum* and *Cleistogenes squarrosa*, the participation of which in the community structure on the biomass is not more than 3–20% (Gunin et al., 2010).

Detailed research on *Allium polyrrhizum* plant communities has been conducted at a station in the Delgertsogt sum of the Middle Gobi aimag (Table 3). The results showed that the studied plant communities are characterized by impoverished species composition: no more than 15 species are noted per 100 m^2. During the maximum growing season, the projective cover of herbage in the studied plant communities varied from 8 to 12% and the total reserves of above-ground biomass were 14–74 g/m^2. Onion prevailed in the onion plant community structure, which formed more than 70% of all biomass. Single instances of grasses of *Stipa krylovii, Agropyron cristatum, and Cleistogenes squarrosa* were found. The desert-steppe species—Mongolian onion or *Allium mongolicum* is noted with small abundance in the plant communities. Other species, including *Caragana leucophloea* and *Carex duriuscula*, *Artemisia adamsii*, *Convolvulus ammanii*, *Potentilla bifurca*, and *Sibbaldianthe adpressa*, are present. The annual and biennial species formed up to 17% of the biomass. The invasiveness coefficient in the studied onion plant communities is 3–10.6, which indicates a strong or very strong disturbance.

We will consider the dynamics of onion plant communities on the example of an MG-X area located on a canopy-sloping plain with medium-power chestnut light loamy soils with significant rubble (Table 4). In the first year of observations in 2009, the lowest phyto-

Table 3. Phytocoenotic characteristics of onion plant communities in the Töv and Dundgovi aimags

Life form, species	25		MG-X		MG-X-1		MG-X-2		MG-X-3		MG-X-4		DTS-3	
	a*	b**	a	b	a	b	a	b	a	b	a	b	a	b
Shrubs														
Caragana leucophloea			0.3	5					1	1.9				
Low shrubs														
Ephedra sinica	25	72.4												
Reaumuria songarica													13.2	50.8
Salsola passerina													10.8	64
Dwarf semishrubs														
Artemisia adamsii							0.7	1.7	0.8	1.5				
Perennial grasses: onions														
Allium mongolicum			0.2	0.2			0.1	0.1						
A. polyrrhizum	11	23.3	10	66.6	6.2	11.5	8.5	16.2	7.5	17.4	7.2	15.9	11.7	22.5
sedges														
Carex duriuscula					0.4	0.5					0.1	0.1	3.2	10.1
forbs														
Convolvulus ammanii					0.5	1					0.5	1	0.8	1.4
Potentilla bifurca					0.1	0.2	0.2	0.2						
Scorzonera divaricata			0.2	0.7										
Serratula centauroides	2	16.5												
Sibbaldianthe adpressa			0.3	0.7	0.3	0.4			0.6	1.1				
Annual-, biennial grasses														
Artemisia pectinata					0.1	0.1								
A. scoparia													0.8	3.1
Bassia dasiphylla									0.1	0.1				
Chenopodium album, Ch. aristatum	7	29.1	0.1	0.3	0.6	0.6	0.8	1.5	1.5	2.9	2.8	3.4	0.6	2.2
Dontostemon integrifolius													2	3.2
Eragrostis minor													0.1	0.1
Total:	45	141.3	11.1	73.6	8.1	14.3	10.3	19.7	11.5	24.9	10.6	20.4	43.2	157.4

a* is projective cover (%) and b** is aboveground phytomass (g/m^2).

coenotic indicators were noted here due to the previous dry years (2005–2008), when the annual amount of precipitations did not exceed 100 mm. *Allium polyrhizum* formed more than 83% of all above-ground mass. In the spring of 2011, there was a fenced-in area here for monitoring of the natural pasture regeneration. In the first two years, no fundamental differences in the plant communities of pastures and the commanded area were observed. In 2011, there were favorable conditions for the development of *Chenopodium aristatum* annual species. The share of *Allium polyrrhizum* was more than 50% of the total above-ground mass. The maximum above-ground mass was noted in 2012, when in a year there were 226 mm of precipitation, and the participation of *Allium polyrrhizum* in the community on the biomass was more than 90%. In the following year, after a number of years with favorable moisture conditions in the communities, the share of forbs increased. In the species composition of the community in reservation conditions, *Stipa krylovii* was

Table 4. Dynamics of dry aboveground phytomass (g/m^2) of the major plant groups in the onion plant community (MG-X)

Life form	2009	2011		2012		2013	
	stocking	stocking	area conservation	stocking	area conservation	stocking	area conservation
Shrubs	0.2	3.4	2.3	5		6.4	1.1
Dwarf semishrubs	0.7				1.7		
Perennial grasses:							
grasses (*Stipa krylovii*)							1.6
onions (*Allium polyrrhizum*)	8.3	28.8	23.6	66.8	59.9	31.2	37.9
sedges	0.2				0.1	0.5	0.2
forbs	0.3	0.8	3.3	1.4	1	6.8	7.3
Annual-, biennial grasses	0.2	15.8	16.4	0.3	0.1	0.1	
Total:	9.9	48.7	45.6	73.6	61	45.1	48

noted for the first time in five years. The share of *Allium polyrrhizum* was 69–79%.

The alkaline-saline depressions are refugiums, from which there is a distribution of *Allium polyrhizum* in the zonal dry steppe plant communities. One of them, which has an *Allium polyrrhizum-Reaumuria songarica-Salsola passerine* plant community with annuals (point DTS-3), was examined 5 km to the east of the MG-X area (Table 3). The desert dwarf subshrub—*Salsola passerine* and *Reaumuria songarica*—are the dominants here. *Allium polyrrhizum* was in good condition, and 34 specimens, on average, were noted per 1 m^2. Its projective cover was about 12%. *Allium polyrrhizum* formed more than 14% of the structure of the above-ground biomass. *Convolvulus ammanii* and annuals of *Artemisia scoparia, Chenopodium album*, and *Eragrostis minor* were noted with small abundance. The distribution of *Allium polyrrhizum* mainly occurs due to the transfer of seeds by different vertebrate species. The most important role in this process is played by the numerous flocks of the migratory Pallas's sandgrouse (*Syrrhaptes paradoxus* Pallas).

The age of mature onion plant communities can be indicated by the results of biomorphometric research. It was revealed that individuals with 14–39 vegetative shoots, 2–16 generative shoots, and a sod diameter of 3–9 cm dominated in the population of *Allium polyrrhizum*, which indicates the maximum development of the *Allium polyrrhizum* population. According to the regularities of ontogenesis of *Allium polyrrhizum*, which are described in detail by Popova (1977) and Cheremushkina (2004), the majority of onion specimens are in a young and average generative state (Fig. 5). This fact allows us to talk correctly about the comparative youth of mature plant communities (25–30 years).

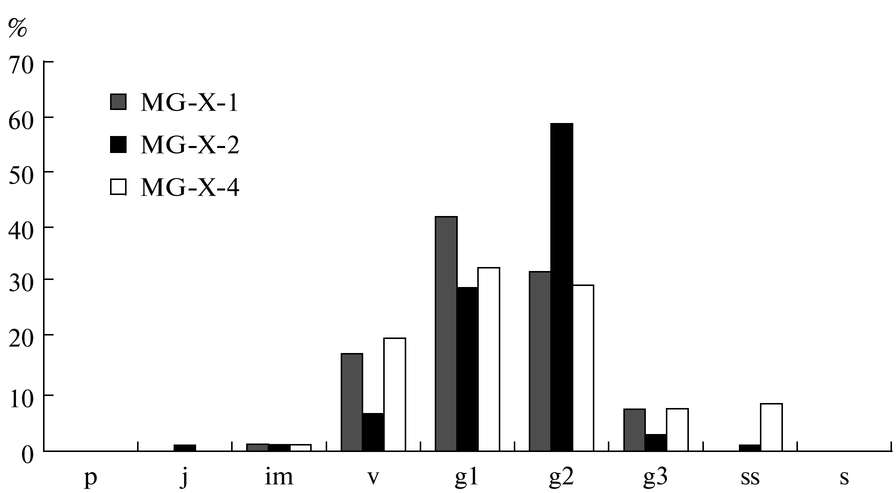

Fig. 5. Ontogenetic population structure of *Allium polyrrhizum* in the dry steppe plant communities: p is seedling, j is juveniles, im is immature, v is virginal, g1 is young generative, g2 is middle-generative, g3 is old generative, ss is subsenile, and s is senile.

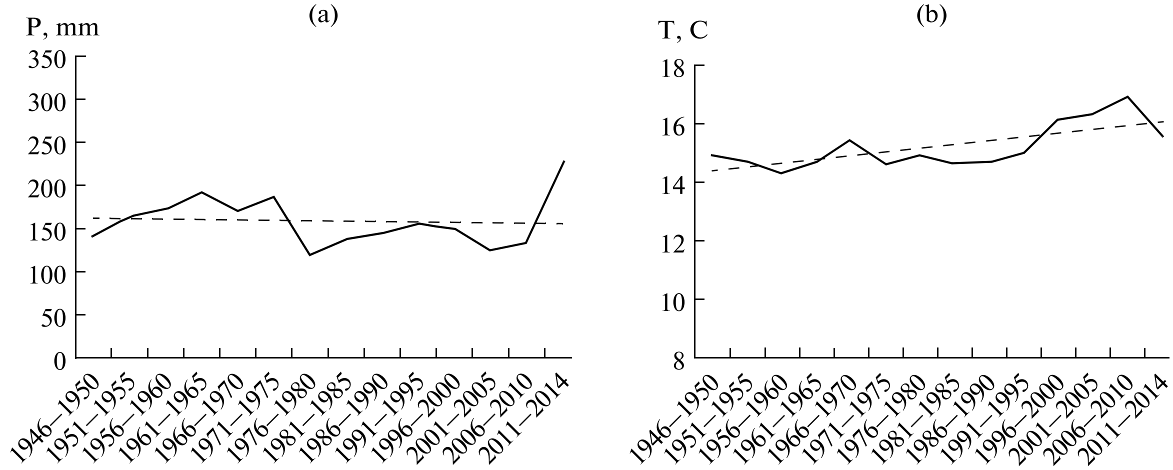

Fig. 6. Dynamics of the average five-year annual precipitation values (a) and the average temperature during the vegetative period (May–September) (b) at the Mandalgovi weather station.

An additional feature indicating the modern distribution processes of *Allium polyrrhizum* in the automorphic ecosystems of dry steppes is its total absence in the ecosystems of uplands and butte ridges. Thus, more than 70% of biomass forms *Artemisia frigid* in the estimated feather-cold sagebrush plant communities with a projective cover of 22.5% and with an above-ground biomass of 118.2 g/m^2, which occupies similar landscape areas; *Stipa glareosa* constitutes 22%, and *Allium polyrrhizum* is completely absent.

The climate data of the Mandalgobi weather station, which is nearest to the station, confirm the arid climate. The wettest year in recorded history was 1964, when there were 370 mm of precipitation, and 1980 was the driest with 76.4 mm. In the five-year cycles, a decrease in precipitation occurred in 1946–1950, 1976–1990, and 1996–2010 (124–149 mm); the periods 1951–1975 and 1991–1995 were wetter, as were the last four years (155–227 mm). The changes in this index are characterized by a negative trend (Fig. 6a). The longest dry periods are noted in 1974–1981 and 2004–2008. The warmest was 2007(4.5°C), and 1947 was the coldest (–0.5°C). The average growing season temperature is 15.2°C. In its long-term dynamics, as well as in five-year cycles, positive trends are noted due to a long period with a temperature rise in relation to the long-term average annual value from 1996 to 2014 (Fig. 6b).

It is known that a feature of sod grasses and firm-bunch onions is the ability to transfer adverse moisture conditions at rest (Bobrovskaya and Nikulina, 2013; Slemnev et al., 1983). In this regard, we undertook a study of the state of resting sod grasses (*Stipa krylovii* and *Cleistogenes squarrosa*) and onions (*Allium polyrrhizum*) in the onion plant communities. The anatomical study of roots showed that 47.4% of the studied sods were dead in *Stipa krylovii*, as were 62% in *Cleistogenes squarrosa* and only 7.6% in *Allium polyrrhizum*. Thus, one may state that *Allium polyrrhizum* has a higher ability to survive drought at rest for a long time compared with the indigenous inhabitants of dry steppes—sod grasses—and the limited moisture content related to it.

The ability of *Allium polyrrhizum* to survive drought periods is attributable to its biological features. It holds and retains atmospheric moisture thanks to the powerful and well-developed sod, the mass of which exceeds the above-ground parts of a plant more than twice. The root system contains thick, threadlike roots with a well-developed, water-bearing parenchyma and is superficially located (at a depth of 30 cm). The majority of the underground organs is concentrated in the upper 10 cm of soil. The mass of the root system exceeds the mass of the above-ground parts by 68 times (Table 5). Therefore, *Allium polyrrhizum* has a fast response even to low precipitation, which allows it to support life during periods of low humidity (Popova, 1977; Bobrovskaya and Popova, 1978).

The physiological and structural features of *Allium polyrrhizum* leaves allow the plant to increase quickly the biomass and sizes of the photosynthetic apparatus during favorable wet periods. The overgrowth is provided by the onion's capacity for a high level of CO_2 assimilation under favorable moisture conditions. Thus, we recorded maximum values in the photosynthesis of this plant, up to 50–60 μmol $CO_2/(m^2\,s)$. It is considerably higher than in the other native species investigated at the same time (Table 6). However, with a fall in air humidity, the onion has a sharp reduction in the rate of CO_2 fixation, which is associated with the need to save water for the support of tissue turgor (Slemnev and Tsooj, 1988; Ivanov et al., 2004). The leaves of the onion have large cells of chlorenchyma—up to 50000 μm^3 or more. This exceeds by 5–10 times the sizes of photosynthetic cells in most other dominant species of steppes. The large sizes of cells allow,

Table 5. *Allium polyrrhizum* phytomass in the onion plant community (MG-X)

Parts of phytomass		Weight g/m^2
Aboveground		44.4
Near-surface-underground		100.0
Underground		3015.2
horizon, cm	fraction, mm	
2–10	>1.0	2068.0
	0.5–1.0	84.0
	0.25–0.5	128.0
	<0.25	121.6
	Total	2401.6
10–20	>1.0	349.2
	0.5–1.0	13.6
	0.25–0.5	14.8
	<0.25	16.4
	Total	394.0
20–30	>1.0	164.0
	0.5–1.0	12.8
	0.25–0.5	24.4
	<0.25	18.4
	Total	219.6
Total phytomass		3159.6

Table 6. CO_2 assimilation by some widespread steppe plant species

Species	CO_2 assimilation, μmol CO_2/(m^2 s)
Allium polyrrhizum	55.0
Agropyron cristatum	23.1
Caragana leucophloea	23.9
Carex duriuscula	20.1
Leymus chinensis	22.7
Stipa krylovii	16.8

on the one hand, leaf overgrowth via tension under favorable conditions. On the other hand, they provide the ability to collect and retain water and to survive under drought conditions.

Thus, the features of the structure and functioning of the photosynthetic apparatus of *Allium polyrrhizum* provide the ability to survive long-term drought periods sufficiently, as well as to respond quickly to short-term wet periods. This allows *Allium polyrrhizum* to occupy territories that are released as a result of the death of competing species due to drought or overgrazing.

Another reason for the distribution of *Allium polyrrhizum* plant communities is the subaerial alkalinization of surface soil horizons, which was noted by us, to alkaline and strongly alkaline mediums (pH—from 8.5 to 9.5) in the steppe ecosystems (Gunin et al., 2010). This process was caused in recent years by a strengthening of wind activity and carry-over on plateau-like plains from the aforementioned alkaline-saline depressions. The strongly alkaline medium is unfavorable for most of the mesophilic and mesoxerophitic steppe and dry steppe grasses. The typical desert xerophytes and halophytes are the most suited to such a situation. These include *Allium polyrrhizum*, which can be attributed to the typical hemixerophyte or mesoxerophyte, which is adapted to living in the conditions of surface soil salinization (Evstifeev and Rachkovskaya, 1977).

CONCLUSIONS

The studies identified the regional features of cross-border interaction between landscapes of the Baikal basin and the Central Asian internal drainage basin. They occur in the conditions of an arid climate and increasing anthropogenic pressure. The character of the digressive processes in the western tip of the Baikal basin is in many ways determined by features of soil covering, in particular, the significant distribution of sand massifs and intensive deflation of sands, as well as the accumulation and transfer of sand deposits in the river valleys. The sand recovery from the desert landscapes of the Great Lakes Depression creates a favorable environment for the development of *Caragana bungei*, which is actively implemented under the canopy of larch forests on sand "tongues" that formed on downwind mountain slopes and river valleys. Pea plant communities formed as a result of these processes in the forest steppes of the Zavkhan aimag. This species of bush can be a serious threat, preventing the reproduction of larch forests in Mongolia. It grows in severe conditions of existence due to the lack of moisture and nutrients, sharp changes in the weather, pasture pressure, fires, illegal fellings, and outbreaks of insect pests.

In the dry steppes near the southern border of the Baikal basin, impoverished monodominant onion plant communities from *Allium polyrrhizum* formed as a result of the alkalinization of soil of the surface soil layer in the zonal cenoses, which are strongly degraded as a result of intensive pasture load and long-term arid climate. The distribution of this species in the plant communities of dry steppes leads not only to a lower forage value of these pastures but to a complete lack of fitness for cattle grazing during the growing season with a view to the high content of toxic substances (Buyantogtokh and Oyuntsetseg, 2009).

On the basis of the analysis of the ecological and physiological features of *Caragana bungei* and *Allium polyrrhizum*, their high degree of adaptation to environmental aridization is defined. The significant predominance of these species in the structure of plant communities allows us to draw a conclusion about long-term and widespread invasive successions and to characterize this process as a special desertification form that represents a greater danger for the preservation of a floristic and faunal diversity and for the further use of the natural potential of transboundary ecosystems in the Baikal basin and the Central Asian internal drainage basin.

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