ISSN 2079-0961, Arid Ecosystems, 2017, Vol. 7, No. 4, pp. 256–264. © Pleiades Publishing, Ltd., 2017.
Original Russian Text © L.A. Dimeyeva, V.N. Permitina, B.M. Sultanova, K. Ussen, V.V. Lyssenko, 2017, published in Aridnye Ekosistemy, 2017, Vol. 23, No. 4(73), pp. 68–78.

APPLIED PROBLEMS OF ARID LANDS DEVELOPMENT

Evaluation of the Restoration Dynamics of the *Artemisia terrae-albae* Communities in the Northern Part of the Aral Sea Region

L. A. Dimeyeva*, V. N. Permitina, B. M. Sultanova, K. Ussen, and V. V. Lyssenko

Institute of Botany and Phyto-Introduction, Ministry of Education and Science of the Republic of Kazakhstan, Almaty, 050040 Kazakhstan

**e-mail: l.dimeyeva@mail.ru*

Received January 29, 2016

Abstract—This article discusses the reclamation dynamics of vegetation cover and soils after the radical phytomelioration of *Artemisia terrae-albae* pastures communities on brown desert solonetzic soils of the northern part of Aral Sea region. The experiment was laid in the late 1970s. *Agropyron desertorum* was used to create the sowing pasture. Plowing led to the destruction of natural plant communities and soils. The low germination of Agropyron seeds promoted the spread of weedy annuals, which slow the demutation of natural vegetation for 10 years. At present, the development of the vegetation cover of the laylands has reached the late-succession stage, for which the spatial and synusial structure of zonal plant communities is typical. The soils are at the stage of reclamation of morphogenetic features and properties according to the type of desert soil formation.

Keywords: Republic of Kazakhstan, northern part of Aral Sea region, vegetation, soils, phytomelioration, demutation

DOI: 10.1134/S2079096117040102

INTRODUCTION

The studies were conducted in the northern Aral Sea region on the territory of the Tereskent Aral Sea Research Station of the Institute of Botany and Phyto-Introduction of the Ministry of Education and Science of the Republic of Kazakhstan in the Shalkarskii (formerly Chelkarskii) region of Aktyubinsk oblast. The research station was organized in 1965 under the supervision of B.A. Bykov, academician of the National Academy of Sciences of the Republic of Kazakhstan (NAS of RK). Complex ecological and geobotanical studies of desert ecosystems were carried out on this territory; "Man and Biosphere," an International Biosphere UNESCO/MAB Program, and ecological and physiological studies and experiments on phytomelioration were also carried out (*Pustynnye statsionary*..., 1988). Substantial results have been achieved in the improvement of degraded pastures; so-called agro-deserts were created. Experiments on the radical, subradical, and superficial improvement of pastures were carried out. Agro-deserts created by the method of subradical improvement demonstrated the promise of an approach for the northern deserts (Bykov and Bedarev, 1968) in which stripes with natural grass and sectors of forage grasses, shrubs or subshrubs alternate on pastures. *Haloxylon aphyllum*[1], *Krascheninnikovia ceratoides*, *Kochia prostrata*, *Agropyron fragile*, and *A. desertorum* were tested as phytomelioration agents. This method was recommended for overgrazed pastures in which the native species did not bear for several years in a row and the seed pool in the soil had been depleted. For 2–3 years after the phytomelioration, the productivity of pastures increased by 2–2.5 times as compared with the initial level (*Productivnost'*..., 1971; Bykov and Savinkin, 1978). Soil slitting and harrowing were carried out for surface improvement; they increased the pasture yield by 25–30% (Beresnev, 1990).

An experiment on radical improvement was carried out in 1978, but its results were not discussed. In this work, we consider two aspects of this issue. First, what are the patterns of secondary succession and reclamation dynamics of soil and vegetation after plowing a site with native vegetation? Secondly, how promising is the use of radical phytomelioration in the northern part of Aral Sea region?

MATERIALS AND METHODS

The northern part of Aral Sea region is a huge region located to the north of the Aral Sea; it covers an area of 66500 square kilometers (*Bioecologicheskie*..., 1968). Based on the physical and geographical zoning of the Aktyubinsk oblast, this territory belongs to the geomorphological region of the Turgai plateau (*Prirodnye usloviya*..., 1969). The arid denudational plateau of the Northern part of Aral Sea region is

[1] Latin nomenclature of the plants is given according to Cherepanova (1995).

divided into the inselberg tablerock highlands, alternating with deep, endorheic solonchak lows in the form of sors and takyrs. The slopes of the inselbergs (cliffs) are steep, with a height of 40–60 m; salt-bearing tertiary clays are exposed there. There are sandy massifs—Bolshie Barsuki and Malye Barsuki—on the denuded plain.

The climate of the region is very dry, moderately hot, SHI[2] <0.4; TC[3], 0.96–1.98 (Bedarev et al., 1971; *Agroclimaticheskie resursy*..., 1974; Dolgikh, 2010). Atmospheric drought[4], as calculated by the SHI is 0.4–0.6; the sum of precipitation for the year is 100–150 mm; the accumulated temperature above +10°C is 3000–3020°C, which indicates the location of the territory in the subzone of the northern deserts. January is the coldest month; the average temperature is –13°C (Saksaulskaya Meteorological Station), and the absolute minimum is –42°C. Summer is dry and hot. The average July temperature reaches +26.8°C, and the absolute maximum is +44°C. The duration of the frost-free period is 226 days. The period with a temperature above 10°C lasts about 173 days. The transitions through 10°C occur on April 17 and October 23. During the year precipitation is prevalent in spring and early summer. The relative air humidity is 77% in winter and 24% in summer. The average wind speed during the year is 3.5 m/s. Northern winds predominate in the cold season. The summer is characterized by the movement of air masses in northwestern, western, and southern directions.

There are no permanent rivers in the northern part of Aral Sea region. Surface waters are temporary; they accumulate due to spring snowmelts and rare rains in sors and takyrs. Tableroch inselbergs have a network of seasonal watercourses, flowing into nearby sore depressions. The groundwater of drained plains are at a considerable depth (50–100 m) and are poorly mineralized (1–2 g/L) (Sergeev, 1937).

The northern part of Aral Sea region belongs to the desert zone, a subzone of the northern desert with development of the brown desert-soil subtype (*Prirodnye usloviya*..., 1969; Novikova et al., 1968). According to natural zoning, the territory is part of the northern desert hollow-and-out plateau of the Aral Sea region with brown soils and sand massifs. Brown normal soils of uplands dominate on the territory. Brown desert solonetzic soils occupy wavy plains and occur along the periphery of the endorheic lows; they are also widely distributed. On the tablerock plateau, brown semimature desert soils are formed. Hilly uplands with steep slopes, vulnerable to erosion, are characterized by the spread of brown desert eroded soils. The lowering of the relief is occupied by meadow solonetz and meadow solonetzic soils. In the endorheic lows solonchak soils are developed.

According to the botanical and geographical zoning, the territory belongs to the Chelkarskii District of the Western North-Turan Subprovince, the North-Turan Province, the Iran-Turan Subregion, the Sahara–Gobi Desert Area within the northern deserts (Rachkovskaya and Safronova, 1994; *Botanicheskaya geografiya*..., 2003).

The vegetation of the northern part of Aral Sea region is represented by two desert types: dwarf subshrub and dwarf subshrub–shrubby (sandy) (Bykov, 1968). Dwarf subshrub deserts develop under conditions of a wavy deluvial-eluvial plain on zonal brown desert soils. Ephemeroid-*Anabasis aphylla-Artemisia terrae-albae* community (*Artemisia terrae-albae* + *Anabasis aphylla* + *Rheum tataricum* + *Poa bulbosa* + *Catabrosella humilis*) dominates on the upland part of the plain (Bykov, 1968). On the inselberg plateaus, there are communities of *Arthrophytum pulvinatum* with the participation of *Asparagus breslerianus*, *Zygophyllum macropterum*, *Ferula nuda*, *Thalictrum isopyroides*, and *Leontice incerta*. Eroded gentle slopes are characterized by the development of complexes of ephemeroid–Artemisia (*Artemisia terrae-albae*, *Poa bulbosa*) and *Anabasis salsa* communities. The dwarf subshrub and shrub sandy deserts occupy the ridge and hilly sands of the Massifs Malye Barsuki and Bolshie Barsuki; shrubs (*Ammodendron bifolium*, *Calligonum commune*, *C.minimum*, *C. murex*, and *Eremosparton aphyllum*) and dwarf subshrubs (*Artemisia tomentella*, *A. arenaria*, and *Kochia prostrata*) dominate here.

Traditional geobotanical and soil methods were used in these studies (*Polevaya geobotanica*, 1959–1976; Bykov, 1978; *Pochvennaya s"emka*, 1959). On 100-m^2 trial plots traced on the ground with a GPS device, detailed geobotanical descriptions of plant communities were carried out. The description was carried out on special forms, including sections reflecting the main components of the landscape (relief, soils), humidification conditions, spatial structure, interrelation with environmental factors, factors affecting vegetation (natural and man-made), etc. The floral composition of the community, phenophase, general and particular projective coverage of the species, and species distribution (by groups and at random) were revealed; for each species height, layer, abundance (according to Drude's scale), and the vital state of the species (according to the A.A. Grossgeim scale) were revealed. An herbarium was collected during the description of plant communities. Unfamiliar plant species was identified during processing of the collected material with the books *Illustrated Guide for Identification of the Plants of Kazakhstan* (*Illyustrirovannyi*..., 1969–1972) and *Flora of Kazakhstan* (*Flora Kazakhstana*, 1956–1966).

[2] SHI, Selyaninov Hydrothermal Index.
[3] TC, index of the biological effectiveness of the climate according to N.N. Ivanov.
[4] Atmospheric drought is a drought that occurs as a result of a lack of precipitation in combination with a high temperature and low humidity, causing plant depression or death.

A trial plot with radical reclamation was laid in 1978 on a slightly inclined plain with *Artemisia terrae-albae* pastures developing on brown desert solonetzic soils. The area of the plot was 1 ha. Phytomelioration methods included real tillage to a depth 20–22 cm with underwinter sowing of *Agropyron desertorum*. The description of the soil and vegetation covers of that period were not maintained, so we applied the analogy method. On the territory adjacent to the reclaimed plot, a test plot of 100 m^2 with natural vegetation that did not undergo attendance was laid. This site was used as a control.

To assess the vegetation cover restoration dynamics, three 4-m^2 sites (2 × 2) each were laid on the meliorated (experimental) and natural (control) sites located at 150 m. At each site, the number of dominants, subdominants, and the most abundant community components were determined. The length-width-height measurements of each specimen of *Artemisia* were measured; the average values were then calculated; the projective cover was determined on their basis. To estimate the number of Artemisia shoots, five sites with an area of 1 × 1 m^2 were laid.

The soil cover was studied on the example of two crossections: on the experimental plot (layland) and on the control site (virgin land). Methodologically, the soils were studied down to the 50-cm level, which is due to the depth of disturbance during plowing (20–22 cm) and possible changes during reclamation in this depth range.

RESULTS

Comparative Analysis of the Morphogenetic Properties of Brown Desert Soils from Sites with Different Land Applications

The brown soils of the studied area, which formed in conditions of deep groundwater occurrence, are characterized by a relatively low thickness of the humus horizon, low humus content, low ash elements content, and low absorption capacity. These soils features are a consequence of the bioclimatic conditions of soil formation (low precipitation and high summer and low winter temperatures), which determine the predominance of xerophytic dwarf subshrubs and saltworts in the plant cover with little participation of grasses and herbage.

Control Site

The brown solonetzic soils of the undisturbed site are characterized by a shallow depth of the humus horizon ($A + B_1 = 30$ cm), soil effervescence from hydrochloric acid from a depth of 26 cm in the presence of visible carbonate precipitation in the profile from a depth of 30 cm, and no secretion of water-soluble salts. The morphological structure of soils is characterized by the presence of a slightly compacted, pale-gray, porous crust ($A_0 = 2$ cm) divided into polygonal separations, under which a humus-eluvial horizon with fluffy consistency and layered structure ($A_1 = 8$ cm) is formed. Below this is the humus-illuvial horizon ($B_1 = 20$ cm), which is dark pale-brown and has a compacted consistency that is fractured with a cloddy structure. Deeper still is the illuvial carbonate horizon ($B_c = 20$ cm), which is heterogeneously yellowish-brown with whitish spots of carbonates and has a firm consistency and a lumpy-nutty structure.

The soils contain a small amount of humus (0.72%) (Table 1) and nitrogen (0.070%) in the surface horizon, which gradually decreases with depth, and a narrow carbon-to-nitrogen ratio, C : N = 4.8–6.0. The amount of carbonates in the upper part of the profile is low; the maximum was found in the illuvial-carbonate horizon. The reaction of the soil solution is slightly alkaline with an increase in alkalinity down the profile. The total number of absorbed bases is small (12.5–17.9 mg-eq per 100 g of soil). Calcium (32–50% of the total absorbed bases) and magnesium (47.5–68% of the total absorbed bases) cations prevail in the composition of absorbed bases. The share of exchangeable sodium accounts 0.9–2.5% of the total absorbed bases. The half-meter layer of soils is not saline by readily soluble salts. According to the granulometric composition of the soil, the soils are clayey with a prevalence of coarse dust fractions (31.87%) and silt (28.24%). The formation of a crust horizon of clayey granulometric soils is due to erosion processes, the transport and deposition of destruction products from the cliff.

Experimental Site

The brown solonetzic soils of the experimental site (laylands) are characterized by a thickness of the humus horizon ($A + B_1$) equal to 29 cm; effervescence from hydrochloric acid from a depth of 29 cm in the presence of visible carbonate precipitation in the profile from a depth of 32 cm, and no secretion of water-soluble salts. The morphological structure of soils is characterized by the presence of a pale-gray, fragile, porous crust ($A_0 = 2$ cm) divided into poorly formed polygonal separations, beneath which a humus-eluvial horizon ($A_1 = 8$ cm) with a fluffy consistency and silty structure is formed. Under it, there is a humus-illuvial horizon ($B_1 = 19$ cm) of pale-brown color with a compacted consistency and silty-cloddy structure. Deeper still is the yellowish-brown illuvial carbonate horizon ($B_c = 21$ cm) with large whitish spots of carbonates, a firm consistency, and a lumpy-nutty structure

The soils contain a small amount of humus (0.75%) (Table 1) and nitrogen (0.070%) in the surface horizon, which gradually decreases with depth, and a narrow carbon-to-nitrogen ratio, C : N = 3.6–6.2. The amount of carbonates in the upper part of the profile is low; the maximum was found in the illuvial-carbonate horizon. The reaction of the soil solution is slightly

Table 1. Comparative indicators of brown desert soils of the studied sites

Depth, cm	Humus, %	Carbon dioxide, %	pH	Total absorbes bases, mg-eq	Exchangeble sodium, %	Total salts, %	∑ Particles <0.01 mm, %
Experimental site							
0–2	0.75	0.22	7.5	10.14	3.0	0.050	16.93
2–10	0.68	0.11	7.8	8.94	3.6	0.037	16.12
10–29	0.44	0.10	8.1	12.69	2.2	0.032	25.41
29–40	0.38	2.39	8.3	15.35	3.4	0.056	33.79
40–50	0.44	3.51	8.6	15.54	6.0	0.077	36.44
Control site							
0–2	0.72	0.25	7.6	12.66	2.4	0.028	60.52
2–10	0.68	0.05	7.7	12.46	2.5	0.018	25.13
10–30	0.58	0.57	8.1	15.84	0.9	0.023	35.26
30–50	0.38	5.31	8.3	17.89	1.7	0.031	41.92

alkaline with an increase in alkalinity down the profile. The total number of absorbed bases is small (8.9–15.5 mg-eq per 100 g of soil). Calcium (47.5–61% of the total absorbed bases) and magnesium (32–44.7% of the total absorbed bases) cations predominate in the composition of the absorbed bases. The ratio of exchangeable sodium accounts for 2.2–6.0% of the total absorbed bases. The half-meter layer of soils is not saline by readily soluble salts. The granulometric composition of the soil is light loamy with a predominance of fine sand (70.08%) and coarse dust (12.09%) fractions.

Studies have shown that the soils of these sites are characterized by a morphological structure of the profile that is typical for the desert type of soil formation. Differentiation of the genetic horizons of the studied part of the soil profile was clearly expressed. The surface crust, humus-eluvial, humus-illuvial, and illuvial carbonate, combined with solonetzic, horizons were discerned. Comparative analysis showed that the layland soils have a humic horizon ($A + B_1$) with a thickness of 29 cm, which is 1 cm less than the thickness of the humus horizon of the control soils. The crust horizon of formerly disturbed soils showed fewer consistences than that of control soils. In the humus-eluvial horizon, there was none of the layering that was inherent to the natural analogs. The structure of the humus-illuvial horizon did not form and was silty, unlike the lumpy structure of the horizon of undisturbed soils. The illuvial-carbonate horizon of disturbed soils retains the morphological features of the original soils in color, consistence, and structure.

The data from the analytical study showed that the amount of humus and total nitrogen in the upper crust horizon of brown soils of long-term laylands corresponds to the control soil values (Table 1). In both cases, the upper part of the soil profile is leached from carbonates; their maximum was observed in the carbonate horizon. Horizons had a slightly alkaline reaction with increasing with depth alkalinity. The total exchangeble bases in the upper horizons was reduced by 2–4 mg-eq/100 g of soil as compared to undisturbed analogs, but a gradual increase of the values with depth was observed in both cases. A half-meter layer of soils in both variants was not saline by readily soluble salts. In the experimental plot soils, the depletion of the silty fraction of the upper horizons was expressed; it appeared after the plowing and the processes of deflation with the removal of earthy material.

Characteristics of the Vegetative Cover from Sites with Different Land Applications

After radical phytomelioration, the sequence of secondary succession at the experimental site was retraced based on diary notes and photographs.

1–2 years: sparse seedling of *Agropyron desertorum*;

3–10 years: stage of weed (*Lappula semiglabra*, *Gyrgensohnia oppositiflora*, *Salsola tamariscina*, and *Polycnemum arvense*) with a single *Agropyron desertorum*;

11–12 years: individual specimens of *Kochia prostrata*;

13–17 years: formation of *Kochia prostrata* community;

18–20 years: introduction of single speciments of *Artemisia terrae-albae*;

21–24 years: formation of *Artemisia terrae-albae*—*Kochia prostrata* community;

From the 25 year: the development of the zonal type vegetation cover (*Artemisia terrae-albae*).

Lappula semiglabra dominated at the weed stage. A thick cover formed in the spring period; it used soil moisture after melting snow and precipitation and limited the germination of other species. After 10 years, the layer of *L. semiglabra* was removed by harrowing, followed by

Fig. 1. Panorama of *Artemisia terrae-albae* communities.

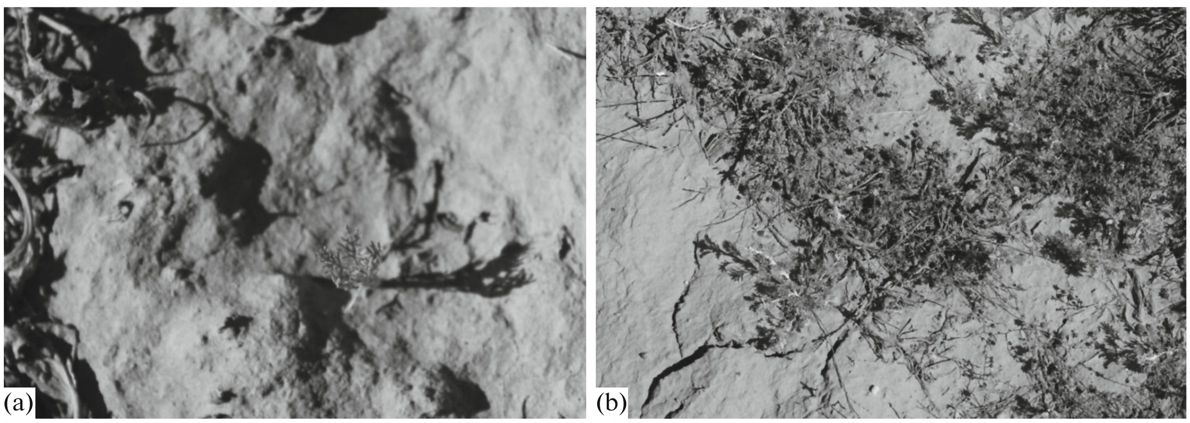

Fig. 2. Sprouts of *Artemisia terrae-albae*. Sites: (a) reclaimed; (b) natural.

the sprouts of *Kochia prostrata*; this forced the formation of a zonal *Artemisia terrae-albae* association.

The studies of the reclaimed (experimental) and natural (control) sites was carried out on June 14, 2015, and May 30, 2016, when most of the ephemerals and ephemeroids were already dried and sloughed; therefore, some of them may not have been taken into account (Fig. 1).

Analysis of Table 2 showed that the floristic richness of the reclaimed site is not much bigger (30 species) than that of the natural site (26 species). Only on the experimental site were noted subshrub *Krascheninnikovia ceratoides*; perennial grasses *Psathyrostachys lanuginosa*, *Tanacetum achilleifolium*, and *Agropyron desertorum*; ephemeroids *Iris songarica* and *Carex pachystilis*; ephemers *Eremopyrum orientale* and *Chorispora tenella*; and annual saltworts *Salsola australis* and Petro*simonia brachiata*. For both sites, the degree of transition of anthropogenic transformation from weak to a moderate was recorded. It is associated with grazing and is indicated by paths, traces of livestock presence, and an abundance of ephemerals.

In the grass canopy of *Artemisia terrae-albae* communities, two main layers were distinguished: the upper one, with a height of 15–30 (40) cm, consisted of *Artemisia terrae-albae* and the lower one, with a height 5–15 cm, consisted of ephemerals. In spring, the generative shoots of ephemeroids (*Poa*, *Tulipa*, *Megacarpaea*) rise to the upper layer, and the *Rheum* flower stalks even exceed it. In the horizontal structure, it is possible to note microgroups of *Climacoptera*, which form spots with an area from 400 to 1700 cm^2, and the number of individuals in such spots varies from 10 to 43. In the spring period, the synusia of ephemeris and ephemeroids are riotous.

Analyses of the size, projective coverage, and the number of the community dominant—*Artemisia terrae-alba*—revealed the following: the average height of the plant community was 31 cm on the natural site and 27.6 cm on the meliorated. The average plant size on the natural site was larger (28.2 cm^2) than on the experimental site (23.3 cm^2). The number of individuals per 100 m^2 was higher in the experimental site (625 copies compared to 508 on the control site). The projective cover of *Atremisia* was also higher on the

Table 2. Species composition of *Artemisia terrae-albae* communities of the studied sites

Species	Reclaimed		Natural	
	2015	2016	2015	2016
	abundance according to Drude's scale			
1	2	3	4	5
Subshrubs and dwarf subshrubs				
Artemisia terrae-albae	sp-cop_1	cop_1	sp-cop_1	cop_1
Anabasis salsa	sol	sol	sol	sol
Anabasis aphylla	sol	sol	sol	sol
Krascheninnikovia ceratoides	sol	un-sol	–	–
Kochia prostrata	–	–	sol	sol
Long-growing perennial grasses				
Stipa sareptana	sol	sol	sol-sp	sol-sp
Psathyrostachys lanuginosa	sol	sol	–	–
Tanacetum achilleifolium	sol	sol	–	–
Agropyron desertorum	–	sol	–	–
Short-growing perennial grasses (ephemeroid)				
Rheum tataricum	sol-sp	sol-sp	sol	sol
Iris songarica	sol	sol	–	–
Megacarpea megalocarpa	sol	sol	sol	sol
Carex pachystilis	sol	sol	–	–
Prangos odontalgica	sol	sol	sol	–
Tulipa buhseana	–	sol	sol-sp	sol-sp
Takhtajaniantha pusilla	–	–	sol	sp
Leontice incerta	–	–	sol	–
Catabrosella humilis	–	sol	sol	–
Poa bulbosa	–	sol-sp	–	sol
Geranium transversale	–	–	–	sol
Allium decipiens	–	un-sol	sol	–
Long-growing annuals				
Climacoptera brachiata	sp-cop_1	sol	sol	–
Gyrgensohnia oppositiflora	sol	sol	sp (cop_1)	–
Polycnemum arvense	sol (sp)	un-sol	sp (cop_1)	sp (cop_1)
Ceratocarpus arenarius	sol	sol	sol-sp	sol
Salsola australis	sol	un-sol	–	–
Polygonum acetosum	sol-sp	–	–	–
Bassia sedoides	–	–	sol	–
Petrosimonia brachiata	–	sol	–	–
Short-growing annuals (ephemer)				
Alyssum turkestanicum	sp	sol	sp-cop_1	sp
Lappula semiglabra	sol	–	sp	cop_1
Ceratocephala testiculata	sol	sol	sp-cop_2	sp
Descurainia sophia	sol-sp	sol	sol	sol
Goldbachia laevigata	sol	–	sol	–
Eremopyrum orientale	sol	sol	–	–
Chorispora tenella	sol	–	–	–
Filago arvensis	sol	un-sol	–	sol
Lichens				
Parmelia vagans	sol	sol	–	–
Total Projective Cover of Community/ Projective Cover of *Artemisia terrae-albae* (%)	56 : 49	55 : 50	47 : 46	60 : 40
Total number of species in the community	27	28	22	18
Total number of species (2015–2016)	30		26	

Table 3. Quantitative indicators of *Artemisia terrae-albae* population renewal

Number of sprouts per 1 m^2		Number of immature speciments per 1 m^2		Survival rate of sprouts of 2015, %
2015	2016	2015	2016	2015/2016
Reclaimed site				
7	71	36	1	14
Natural site				
30	108	6	9	30

reclaimed site. Differences in the number of shoots and immature specimens of *Artemisia terrae-albae* were revealed (Fig. 2; Table 3). The number of sprouts on the control site was 1.5–4 times higher. The count of the immature individuals (last year's shoots) showed that their number was greater on the reclaimed site in 2015 and on the natural one in 2016. The survival rate of *Artemisia* sprouts in 2015 was two times higher on the control site. Studies conducted at the research station in the late 1960s (*Bioecologicheskie*..., 1968) showed that the main cause of death of *Artemisia* sprouts was soil surface drying; the number of surviving seedlings was often less than 1% of the number of spring sprouts.

DISCUSSION

Land plowing refers to the strong degree of anthropogenic disturbance due to the destruction of the integrity of the structure and consistency of the upper part of the humus horizon, the mixing of horizons, a decrease in the organic matter supply as a result of vegetation destruction, and a decrease in humus and nutrients content.

Based on the conducted studies, it can be assumed that, during the period after plowing in 1978 and until the survey in 2016, brown desert soils restored differentiation on the genetic horizons. The upper horizons, which were disturbed by plowing, are now characterized by a less dense consistency and more weakly formed structure in comparison with the soils of the control site. The soil chemical composition is similar to the indices of control soils in terms of humus, total nitrogen, and carbon dioxide of carbonates content and their redistribution along the soil section. The total absorbed bases in the upper part of the section is reduced in comparison with the control soils, which correlates with changes in the granulometric composition. The granulometric composition of the soils of the experimental site changed as a result of deflation and water erosion with the removal of the earthy part and the sanding of the disturbed horizons.

Artemisia terrae-albae predominates in the vegetation cover of both sites; this allows the conclusion that the vegetation of the disturbed area is at the final stage of demutation. Subshrub *Krascheninnikovia ceratoides*, dwarf subshrub *Anabasis salsa*, sod grass *Stipa sareptana,* and annual saltworts *Climacoptera brachiata* and *Salsola australis* participate in the community on this site; they are typical for the original zonal communities. On both sites there are sporadic representatives of *Anabasis salsa*, which indicate solonetzic soils. Participation in the communities of *Stipa sareptana* is typical for the subzone of the northern deserts. Ephemeroids also grow on the natural site (*Takhtajaniantha pusilla*, *Leontice incerta*, and *Geranium transversale*); they are indicators of the occupancies of ecological niches. The species composition and variance in the projective coverage of annual saltworts (*Climacoptera brachiata*, *Gyrgensohnia oppositiflora*, *Polycnemum arvense*, and *Salsola australis*) are associated with the processes of local anthropogenic disturbances. The absence of *Kochia prostrata* on the experimental site is determined by the sequence of secondary succession, changes in the species composition and phytocenotic role, and the occupancies of ecological niches by *Artemisia terrae-albae*. The participation of *K. prostrata* in natural communities is caused by local disturbances of an average degree. In the conditions of the northern Aral Sea, this species does not form communities. *K. prostrata* dominates only in serial associations in sandy deserts (Kurochkina, 1966).

The development of *Artemisia terrae-albae* communities is caused by the formation of specific soil conditions determined by the optimal consistency density, pronounced structure, and presence of humus. The sanding of the upper horizons of layland soils explains the presence of such species as *Krascheninnikovia ceratoides*, *Psathyrostachys lanuginosa*, and *Carex pachystilis*, which indicate a lighter granulometric composition.

An increased fine sand fraction in the surface layers of *Agropyron desertorum—Artemisia terrae-albae—Ceratocarpus arenarius* communities of the research station was noted previously (Lysenko and Shabanova, 1990); a higher soil moisture in agrocenoses as compared with virgin soil has also been found. This explains the presence of a larger number of ephemeral species and the sporadic occurrence of the ephemeroid *Iris songarica*.

In light of the sequence of progressive succession, it can be stated that the late-succession stage, which is characterized by a spatial and synuzial structure of zonal plant communities, was reached 38 years after the plowing of the site occupied by *Artemisia terrae-albae* communities.

Without detailed measurements and soil analyses, it would be difficult to identify differences. Visually, both sites are practically the same. All of the differences are stacked in variations of series properties within the parameters of the brown desert saline soils with appropriate plant communities: ephemers–*A. terra-albae* (*A. terra-albae*, *Alyssum turkestanicum*, *Ceratocephala testiculata*, *Eremopyrum orientale*, etc.); ephemeroid–*Anabasis aphyla*–*Artemisia terrae-albae* (*A. terra-albae*, *Rheum tataricum*, *Catabrosella humilis*, etc.), and feather-grass–*Artemisia terrae-albae* (*A. terra-albae* and *Stipa sareptana*). Subdomination is mainly due to the lighter granulometric composition and smaller amount of water-soluble salts in the surface horizons (Lysenko and Shabanova, 1990), which are determined by the landscape location, microrelief, and local anthropogenic disturbances.

Another aspect of the research is the possible use of radical improvement methods for the restoration of rough pasture. The need to perform radical phytomelioration is connected with the degradation of natural grasslands and the impossibility of their self-restoration. In the northern deserts, the main difficulties of radical reclamation of pastures are the insufficient amount of precipitation and unfavorable physical and chemical properties of brown desert solonetzic soils for the growth of phytomelioration plants. Bykov and Savinkin (1978) mentioned the unacceptability of the radical reclamation of *Artemisia terrae-albae* pastures in the northern part of Aral Sea region because of strong wind erosion; they recommended a semiradical or strip reclamation with 3–6 m width of strips and 20 m of virgin land between the strips. However, the experiment was conducted, and only now can we illustrate its consequences.

There is no need for radical improvement. The possibilities for the natural restoration of severely degraded pastures are presented in the stability potential of the plant communities themselves. We conducted soil and geobotanical studies on degraded pastures near the village Shokysu, 7 km from the research station, on a site similar to the control site with a weak pasture load. The vegetative cover was represented by an ephemeral–*Artemisia terrae-albae*–*Anabasis aphylla* community (*Anabasis aphylla*, *Artemisia terrae-albae*, *Ceratocephala testiculata*, and *Eremopyrum triticeum*). The total projective coverage of the community was 50%. *A. terrae-albae* occupies only 5%, *Anabasis aphylla*, 10%, *Ceratocephalus* and *Eremopyrum*, 20%, and *Ceratocaprus arenarius*, 10%. *Peganum harmala*, *Climacoptera brachiata*, and *Londesia eriantha* were also represented in the community. The differences in vegetation cover as compared to the control site communities are quite sharp. The dominant role of *A. terrae-albae* passed to *Anabasis aphylla*, an indicator of disturbances. The total projective coverage of the community was reduced by 5–10%, and the projective coverage of the dominant species decreased by 35–40% (seven to eight times). The disturbed soils do not have a formed crust, and the contents of humus, total nitrogen, and carbon dioxide of carbonates in the upper horizons is half that in comparison with control soils.

Since *A. terrae-albae* participates in communities even with strong disturbances, it is possible to expect that, in the case of protection regime compliance, the restoration of *Artemisia* dominant role is possible within 5 years and that complete restoration would take from 15 to 20 years (Kirichenko, 1982). Activities for the semiradical improvement of pastures and rangeland rationing should be taken to enforce demutational succession and increase productivity.

CONCLUSIONS

Analysis of the restoration dynamics of soil and vegetation cover after reclamation measures, including real tillage to 20–22 cm depth, showed that the late-succession stage, which is close to the climax, was reached in 38 years. The early-succession (weed) stage lasted for 10 years. The marker of the transition to the middle-succession stage was the introduction of *Kochia prostrata*; hereafter, a *Kochia prostrata* community, which is not typical for zonal ecosystems, was formed. The first specimens of *A. terrae-albae* appeared in 18–20 years of demutational succession. The late-succession stage occurred 25 years after the disturbances and continues at the present time. The features that are common to the climax community are the coincidence of the species composition; the horizontal and vertical structure of the phytocenosis and the rhythms of development for the vegetation cover; and differentiation of the genetic horizons, humus content, total nitrogen content, and carbon dioxide of carbonates content for the soil cover. Differences are exhibited in the features of *Artemisia* renewal (a smaller number of sprouts and their survival rate) and slightly higher species richness. For soils that are in a prolonged recovery stage, the upper horizons, disturbed by plowing and their sanding, are observed to have a poorly formed structure.

Analysis of the radical phytomelioration of *Artemisia terrae-albae* communities on brown solonetzic soils showed that this method of pasture improvement should be carefully applied in the zonal plant communities of the northern part of Aral Sea region. Plowing has led to the destruction of natural plant communities and soil degradation. The sowing of *Agropyron* had no positive results, and the secondary succession for 10 years remained at the stage of weedy annuals. To create a seeded pasture, a monoculture of *Agropyron desertorum* was chosen. The low seed germination could be caused by unfavorable weather conditions, as well as by poor seed quality. The most successful results for "agro-desert" creation were achieved in experiments with sowing a seed mixture of shrubs, subshrubs, and grasses (Shamsutdinov, 1979; Nechaeva et al., 1978; Nechaeva, 1989; *Teoreticheskie osnovy...*, 1973; etc.), which allow more complete usage of ecosystem resources and the creation of productive pastures in different climatic conditions.

ACKNOWLEDGMENTS

The researchers were supported by the project "Sustainable Functioning and Opportunities for the Rehabilitation of Zonal Ecosystems of the Northern Part of the Aral Sea region" of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan.

REFERENCES

Agroklimaticheskie resursy Aktyubinskoi oblasti Kazakhskoi SSR (Agroclimatic Resources of Aktyuba Region of Kazakh Soviet Republic), Leningrad: Gidrometeoizdat, 1974.

Bedarev, S.A., Gerasimenko, G.Yu., and Korobova, E.N., Climatic characteristic of Northern Aral region, in *Produktivnost' pastbishch Severnogo Priaral'ya* (Productivity of Pastures of Northern Aral Region), Moscow: Gidrometeoizdat, 1971, pp. 5–22.

Bioekologicheskie osnovy izpol'zovaniya i uluchsheniya pastbishch Severnogo Priaral'ya (Bioecological Basis of Use and Improvement of Pastures of Northern Aral Region), Bykov, B.A., Ed., Alma-Ata: Nauka, 1968.

Botanicheskaya geografiya Kazakhstana i Srednei Azii (v predelakh pustynnoi oblasti) (Botanical Geography of Kazakhstan and Central Asia within the Desert Region), St. Petersburg: Boston-Spektr, 2003.

Bykov, B.A., Vegetation, in *Bioekologicheskie osnovy izpol'zovaniya i uluchsheniya pastbishch Severnogo Priaral'ya* (Bioecological Basis of Use and Improvement of Pastures of Northern Aral Region), Bykov, B.A., Ed., Alma-Ata: Nauka, 1968, pp. 25–34.

Bykov, B.A., *Geobotanika* (Geobotany), Alma-Ata: Nauka, 1978.

Bykov, B.A. and Bedarev, S.A., Rational use and improvement of pastures of Northern Aral region, in *Bioekologicheskie osnovy izpol'zovaniya i uluchsheniya pastbishch Severnogo Priaral'ya* (Bioecological Basis of Use and Improvement of Pastures of Northern Aral Region), Bykov, B.A., Ed., Alma-Ata: Nauka, 1968, pp. 127–133.

Bykov, B.A. and Savinkin, A.P., Improvement of wormwood and Biyurgun pastures, in *Struktura i produktivnost' rastitel'nosti pustynnoi zony Kazakhstana* (The Structure and Productivity of the Plant of Steppe Kazakhstan), Alma-Ata: Nauka, 1978, pp. 126–129.

Dolgikh, S.A., Analysis of main climatic parameters affecting desertification processes, in *Respublika Kazakhstan* (The Kazakhstan Republic), Almaty: Print-S. 2010, vol. 3, pp. 206–210.

Flora Kazakhstana (Flora of Kazakhstan), 9 vols., Alma-Ata: Akad. Nauk KazSSR, 1956–1966.

Illyustrirovannyi opredelitel' rastenii Kazakhstana (Illustrated Guide for Identification of the Plants of Kazakhstan), 2 vols., Alma-Ata: Nauka, 1969–1972.

Kirichenko, N.G., Anthropogenic shifts in pasture clay deserts, in *Smeny pustynnoi i subal'piiskoi rastitel'nosti pri pastbishchnom ispol'zovanii* (Shifts of Desert and Subalpine Vegetation after Pasture Use), Alma-Ata: Nauka, 1982, pp. 34–48.

Kurochkina, L.Ya., Vegetation of the sand deserts of Kazakhstan, in *Rastitel'nyi pokorv Kazakhstana* (Vegetation Cover of Kazakhstan), Alma-Ata: Nauka, 1966, vol. 1, pp. 191–592.

Lysenko, V.V. and Shabanova, L.V., Functions and dynamics of background communities, in *Kompleksnaya kharakteristika pastbishch pustynnoi zony Kazakhstana* (Complex Characteristic of Pastures of the Desert Zone of Kazakhstan), Alma-Ata: Nauka, 1990, pp. 97–138.

Nechaeva, N.T., Ecological basis for conservation and enrichment of pastures of the arid zone of Soviet Union, *Probl. Osvoeniya Pustyn*, 1989, no. 2, pp. 3–13.

Nechaeva, N.T., Shamsutdinov, Z.Sh., and Mukhamedov, G.M., *Uluchshenie pustynnykh pastbishch Srednei Azii* (Improvement of Desert Pastures of Central Asia), Ashkhabad: Ylym, 1978.

Novikova, A.G., Storozhenko, D.M., Bikmukhamedov, M.A., and Tyurmenko, A.N., *Pochvy Kazakhskoi SSR. Pochvy Aktyubinskoi oblasti* (Soils of Kazakh SSR. Soils of Aktyuba Region), Alma-Ata: Nauka, 1968, no. 11.

Pochvennaya s"emka. Rukovodstvo po polevym issledovaniyam i kartirovaniyu pochv (Soil Survey: Manual for Field Tests and Soil Cartography), Moscow: Akad. Nauk SSSR, 1959.

Polevaya geobotanika (Field Geobotany), 5 vols., Moscow: Nauka, 1959–1976.

Prirodnye usloviya i estestvennye resursy SSSR. Kazakhstan (Natural Conditions and Resources of Soviet Union: Kazakhstan), Moscow: Nauka, 1969.

Produktivnost' pastbishch Severnogo Priaral'ya (Productivity of Pastures of Northern Aral Region), Moscow: Gidrometeoizdat, 1971.

Pustynnye statsionary Kazakhstana i Srednei Azii (Desert Stationers of Kazakhstan and Central Asia), Alma-Ata: Nauka, 1988.

Rachkovskaya, E.I. and Safronova, I.N., New map of botanical-geographic zonation of the desert area of Kazakhstan and Central Asia, in *Geobotanicheskoe kartografirovanie* (Geobotanical Cartography), St. Petersburg: Nauka, 1994, pp. 33–49.

Sergeev, V.A., *Gruntovye vody Prikaspiiskikh i Priaral'skikh pustyn'* (Ground Waters of Caspian and Aral Deserts), Leningrad: Lening. Gos. Univ., 1937.

Shamsutdinov, Z.Sh., Theory and practice of phytomelioration of desert pastures, *Probl. Osvoeniya Pustyn*, 1979, no. 6, pp. 27–37.

Teoreticheskie osnovy i metody fitomeliroatsii pustynnykh pastbishch Yugo-Zapadnogo Kyzylkuma (Theoretical Basis and Phytomelioration of Desert Pastures of the Southwestern Kyzyl Kum Desert), Momotov, I.F., Ed., Tashkent: Fan, 1973.

Translated by T. Kuznetsova