# Ecological restoration of biodiversity and forage productivity of degraded pasture ecosystems in the Central Asian Desert

*Zebri* Shamsutdinov*

Federal Williams Research Center of Forage Production & Agroecology, 141055, k.1, Nauchnyi gorodok str., Lobnya, Moscow Region, Russian Federation

**Abstract.** The low productivity of pastures and its sharp fluctuations in the desert regions of Central Asia are due to the natural-historical factors of this natural zone. However, in recent years, these shortcomings of pastures have been further aggravated as a result of the rapid growth of the population, the continuous development of industry and transport in desert areas, and the pressure of anthropogenic and man-made factors on vegetation and soil is increasing from year to year. This caused disruption of the structure and normal functioning of pasture ecosystems, and their degradation. Mass degradation of pasture ecosystems in arid regions of Central Asia occurs in a short time, which dictates the need for environmental restoration of these destroyed pasture lands. The United Nations General Assembly, by resolution 73/284, adopted at the 69th plenary meeting on March 1, 2019, decided to proclaim 2021-2030 as the "United Nations Decade for the Restoration of Degraded Ecosystems" and called on UN member states to help strengthen political will, mobilize available resources, strengthening scientific studies on ecosystem restoration at the global, regional, national and local levels. To restore the lost biodiversity of the forage productivity of degraded pasture ecosystems in the Central Asian Karnabchul Desert, dominant species of forage plants were sown in the following ratio: Haloxylon aphyllum (15 %), Halothamnus subaphyllus (20 %), Artemisia diffusa (50 %) and Poa bulbosa (15 %). The conducted studies allow to conclude that use of zonal-typical life forms of dominant species of forage plants and sowing of their mixtures (combinations) ensures formation of multi-species multi-level pasture ecosystems with high and stable forage productivity over the years in the Central Asian desert. The restored multi-level and multi-species pasture ecosystems are endowed with the property of self-renewal and self-maintenance of the structural and functional organization. The restored multi-species shrub-semi-shrub-herbaceous pasture ecosystems with a characteristic set of species inherent in natural pasture communities are characterized by high stable forage productivity and perform a conservation function in the Central Asian desert.

* Corresponding author: aridland@mail.ru

## 1 Introduction

The current state of desert pastures is characterized by a disturbed structure and destabilized functions [1]. Their productivity does not exceed 0.15-0.3 t/ha of fodder in terms of dry matter. In addition, the productivity of desert pastures is highly dependent on meteorological conditions, therefore, it fluctuates sharply over the years and seasons. In favorable years, a hectare of pastures in deserts provides twice as much feed in relation to the average harvest year, in unfavorable years it decreases by 3-5 times. Depending on the hydrothermal conditions, in each decade there are three fruitful, four medium-productive, and three lean years [2].

The yield of desert pastures and their nutritional value vary not only depending on the year, but also on the season of the year. Thus, the amount of forage for winter on pastures decreases 2.5 times, the protein content in pasture forage of Kyzyl Kum decreases from 20 to 5 %, protein — from 13 to 4 %. 100 kg of dry pasture feed in spring contains 80-90 fodder units, in winter — 18.3 fodder units [3].

The low productivity of pastures and its sharp fluctuations in the desert regions of Central Asia are due to the natural-historical factors of this natural zone. However, in recent years, these shortcomings of pastures have become even more aggravated due to improper human activities in desert areas. As a result of the rapid growth of the population and the continuous development of industry, transport in desert areas, the pressure of anthropogenic and man-made factors on the vegetation and soil cover increases from year to year, which has caused a disruption in the structure and normal functioning of pasture ecosystems, and their degradation.

The current massive degradation of pasture ecosystems in arid regions of Central Asia occurs in a short time that dictates the need for ecological restoration of these destroyed pasture lands [4, 5].

The United Nations General Assembly, by resolution 73/284, adopted at the 69th plenary meeting on March 1, 2019, decided to proclaim 2021-2030 as the "United Nations Decade for the Restoration of Degraded Ecosystems" and called on UN member states to help strengthen political will, mobilize available resources, strengthening scientific studies in the field of ecosystem restoration at the global, regional, national and local levels [6].

In this context, the goal of our paper is to develop the methods for restoring lost biodiversity and forage productivity of degraded pasture ecosystems in the Central Asian desert based on the theory of restoration ecology.

## 2 Methods

To restore the lost biodiversity and forage productivity of degraded pasture ecosystems in the Central Asian desert Karnabchul seeded dominant species of forage plants – shrubs: black saxaul (Haloxylon aphyllum) – 15 %, Halothamnus subaphyllus – 20 %, half-shrub Artemisia branchy (Artemisia diffusa) – 50 % and the ephemeroid Poa bulbosa (15 %). Phenological observations, biometric records of plant growth, development, and phytomass formation were carried out according to the method [7].

The studies were carried out in the Karnabchul desert in the territory of the Karnab farm (Samarkand region, Uzbekistan). Soils – light gray soils, medium and light loamy. The average annual air temperature is +16 °C, in June-July – 40-45 °C. The amount of precipitation is 180-250 mm. Relative air humidity is at the level of 30 % [8].

## 3 Results

The structural organization of the shrub-semi-shrub-herbaceous (ephemeroid) ecosystem consists of four layers interacting with each other occupied by ecological niches.

The arboreal shrub black saxaul (Haloxylon aphyllum (Minkw) I1jin) occupies the first, upper dominant layer in the restored ecosystem. The height of black saxaul is 350-400 cm, life expectancy is 60-90 years.

Black saxaul is a hyperxerophyte, extremely resistant to air and soil drought, extreme heat and dry air. It is sufficiently resistant to soil salinity, it is characterized by the phenomenon of a salt effect, that is, an improvement in growth processes in presence of a certain amount of chloride-sulfate type salts in the root layer of the soil. Black saxaul is characterized by wide ecological plasticity; it grows on loamy, sandy loam, takyr-like soils, takyrs, as well as on highly saline soils. It grows quickly in culture, gives a high yield of forage mass. Black saxaul has a high growth capacity. Shoots are formed when the aboveground part is alienated at the height of 30 - 40 cm from the soil surface, especially intensively at the age of 2-3 to 12-15 years. The root system is powerfully developed and deeply penetrating into the soil – up to 12.5 m, adapted to use of all forms of moisture – atmospheric, condensation, groundwater.

Black saxaul is endowed with high phyto-reclamation and pricing ability. It goes well with dwarf shrubs and grasses forming multicomponent stable and highly productive pasture agrophytocenoses.

According to L.G. Ramenskiy [9], Grime [10], according to the adaptive strategy – violent has the ability to maintain a stable water balance and a normal state of water content in extremely harsh desert climate conditions, which provides resistance to drought and tolerance to salt stress [8].

The second level is occupied by populations of Halothamnus subaphyllus ((CAMey.) Botsch.). Plants 70-150 cm high, with root systems reaching the depth of 6 m in the soil. It has a long growing season – 235-250 days, life expectancy – 8-12 years. An excellent plant for creating autumn-winter pastures – hyperxerophyte is distinguished by its extreme ecological resistance to a complex of abiotic stress – air and soil drought, heat, dry winds, strong winds.

Halothamnus subaphyllus is an ecologically plastic species capable of growing both on clay and sandy soils. In culture, it rapidly grows and develops reaching the height of 50-60 cm in the first year of life and often enters the generative phase. It differs in stable fodder productivity (1.2–1.7 t/ha) of dry fodder mass, contains up to 24.7 % of protein. It renews well after the alienation of the aboveground part (at the height of 40 cm from the soil surface). It has high competitive resistance in crops in a mixture with black saxaul, eastern Halothamnus subaphyllus, wormwood and ephemera.

Spreading wormwood (Artemisia diffusa Krasch.) forms the third layer in the vegetation cover of restored shrub-semi-shrub-herbaceous pasture ecosystems. In the above-ground sphere, the plant height is 25 cm, the roots occupy the soil thickness – 0-115 cm, the lateral roots break up into many roots of the second, third and subsequent orders with numerous absorbing roots.

The fourth level of herbaceous plants is ephemeroid and ephemeral. Their height in the above-ground sphere does not exceed 18-20 cm, and the roots occupy a surface soil niche – 0-15 cm forming a sod.

In the first two years after creation of a pasture agrophytocenosis in the herbage, ephemera are rare, in subsequent years their number rapidly increases and for 4-5 years there are 1800-2350 ths ephemera and ephemeroids per hectare. From the 5th year of agrophytocenosis life, the abundance of ephemera and ephemeroids mainly depends on precipitation in the spring. The maximum of ephemera and ephemeroids was recorded at the 7th year of life – 1015 pcs/m$^2$. At the age of 8-10 years, the agrophytocenosis was fully formed and turned into a shrub-semi-shrub-herbaceous pasture ecosystem with a stable number of plants and productivity, which is an example of a sustainable community.

Our observations showed that under the canopy of black saxaul sown together with it, Halothamnus subaphyllus and wormwood are found in large numbers and in a good vital condition, ephemera – insignificantly, mainly Schismus arabicus, Herniaria hirsuta, Hordeum leporinum, Heliotropium dasycarpum. The projective coverage of ephemerals is 5-10 %. In the intercrown areas, the ephemeral cover of agrophytocenosis, depending on the meteorological conditions of the year, consists of 21-39 species (table). Their projective cover is very high – 50-60 %, on the curb ring up to 90-95 %.

**Table.** Species composition of ephemera in the shrub-semi-shrub-herbaceous ecosystem.

| Plant | Abundance according to Druda | | | |
|---|---|---|---|---|
| | 1st year | 2nd year | 3rd year | 4th year |
| Alyssum desertorum | sp | sp | sol | sp |
| Amaranthus retroflexus | – | sol | – | sol |
| Aphanopleura capilifolia | sol | sp | sol | sol |
| Astragalus filicaulis | sol | sp | sol | sol |
| Astragalus campylorhynchus | sol | sol | – | sol |
| Boissiera pumilio | sp | $cop_1$ | sp | $cop_1$ |
| Bromus danthoniae | sp | cop | sp | sp |
| Bromus tectorum | $cop_1$ | $cop_1$ | $cop_1$ | $cop_1$ |
| Bromus scoparius | – | – | – | sol |
| Ceratocarpus utriculosus | sol | sol | sol | sol |
| Convolvulus fruticosus | – | – | sol | – |
| Descurainia sophia | – | sol | – | sp |
| Diarthron vesiculosum | – | – | – | sol |
| Eremodaucus lehmannii | sol | sol | – | sol |
| Eremopyrum orientale | sol | sp | sol | sp |
| Eremopyrum hirsutum | sol | sol | sol | sp |
| Euclidium syriacum | – | sp | sp | sp |
| Heliotropium dasycarpum | – | sol | – | sol |
| Herniaria hirsuta | – | sol | sol | sol |
| Hordeum leporinum | sol | sol | sol | sol |
| Holosteum umbellatum | sol | sol | sol | sol |
| Hypecoum parviflorum | – | sol | sol | sol |
| Ixiolirion tataricum | sol | sol | sol | sol |
| Koelpinia linearis | sol | sol | sol | sp |
| Lappula microcarpa | sol | sol | sol | sol |
| Lallemantia royleana | – | – | – | sol |
| Leptaleum filifolium | sp | sp | sp | sp |
| Malcolmia turkestanica | sp | $cop_1$ | sp | $cop_1$ |
| Matricaria lamellate | – | – | – | sol |
| Meniocus linifolius | – | – | sol | sol |
| Nardurus krausei | sol | sp | sol | sp |
| Nigella integrifolia | – | – | – | sol |
| Papaver pavoninum | – | sol | sol | sol |
| Poa bulbosa | sp | $cop_1$ | $cop_1$ | $cop_1$ |
| Psylliostachys spicata | sol | sol | sol | sol |
| Salsola nitraria | – | – | – | sol |
| Schismus arabicus | sol | sol | sol | sol |
| Stellaria holostea | – | sol | – | sol |
| Trigonella grandiflora | sp | $cop_1$ | sp | sp |

| Plant | Abundance according to Druda | | | |
|---|---|---|---|---|
| | **1st year** | **2nd year** | **3rd year** | **4th year** |
| Trisetum cavanillesii | – | sol | sol | sol |
| Veronica campylopoda | sol | sol | – | sol |
| Ziziphora tenuior | – | sol | – | – |

The ephemeral cover is based on Bromus tectorum, B. danthoniae, Boissiera pumilio, Trigonella grandiflora. Quite a lot of Leptaleum filifolium, especially in wet years. These ephemerals account for up to 95 % of the crop of the herbaceous cover of the agrophytocenosis.

The half-crown and intercrown microphytocenoses differ sharply not only in the species composition and number of species, but also in the height of the herbage: in the half-crown, the height of ephemera does not exceed 8-10 cm, in the intercrown – 18-25 cm. Ephemera grow especially strongly in the ecotone between the described microphytocenoses, reaching 35-40 cm in height, which indicates the edge effect, due to favorable conditions of soil moisture. It is appropriate to note here that more moisture accumulates under the canopy of black saxaul than in open pastures and intercrown areas.

Forage productivity of restored pasture ecosystems. The figure shows data characterizing the forage productivity of the restored multicomponent shrub-semi-shrub-herbaceous pasture ecosystem.

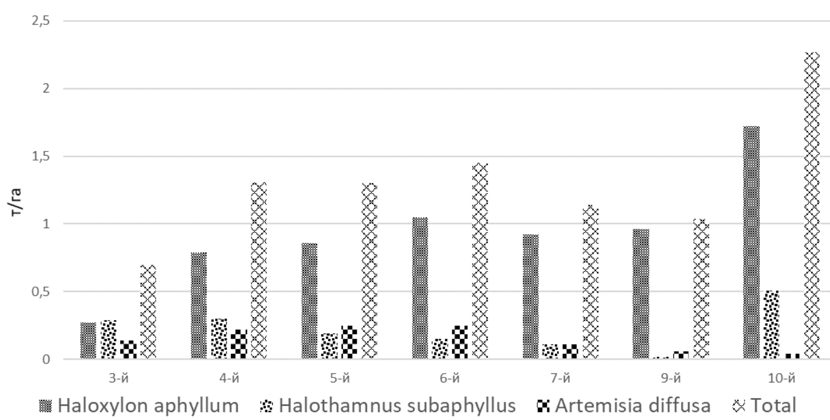


**Fig.** Forage productivity of shrub-semi-shrub-herbaceous pasture ecosystem.

At the 3rd year of life, when agrophytocenosis is recommended for use for grazing, the total fodder reserve of its constituent plants is 2 times higher than that of natural wormwood-ephemeral pastures (0.36 t/ha) of Karnabchul. Later, up to 9 years of age, the fodder productivity of the restored pasture ecosystem is continuously increasing and stabilizing. This agrophytocenosis has accumulated the maximum forage productivity by the 10th year of life, which can be seen from the figure.

Halothamnus subaphyllus and spreading wormwood are distinguished by unstable yield. Sharp fluctuations in the yield of Halothamnus subaphyllus are associated with a widespread affecting at 7-9 years of life by rust and powdery mildew. In spreading wormwood, a decrease in yield is the result of the influence of the competitive power of populations of black saxaul and dense ephemeral herbage. Due to such changes, the share of participation of wormwood in the total forage productivity of agrophytocenosis decreases from 20.0 to 1.8 %. The basis of fodder production (Fig.) is black saxaul (38.6-94.1 %).

It shall be noted that ephemera and ephemeroids that have appeared in the composition of pasture agrophytocenoses, starting from 5-7 years of age, accumulate significant (0.17-0.35 t/ha) fodder products.

## 4 Discussion

To restore the lost biodiversity of degraded pastures in the Central Asian Desert, the woody shrub black saxaul (Haloxylon aphyllum), the forage shrub of Halothamnus subaphyllus, the wormwood (Artemisia diffusa), and the bulbous bluegrass ephemeroid (Poa bulbosa) were used.

When selecting forage plants for phytomeliorants, the following basic principles of the theory of restoration ecology were based [11].

The principle of floristic and cenotic abundance of phytocenoses and its significance for substantiating the possibility of ecological restoration of degraded pasture ecosystems. The overwhelming majority of natural pasture communities in their modern form are incomplete, i.e. they lack species capable of growing under these conditions with a sufficient supply of their primordia [12]. The concept of the fullness of phytocenoses was first introduced into science by L.G. Ramenskiy [13].

According to L.E. Homeland [14], natural pasture ecosystems in arid zones of Central Asia, without exception, are secondary anthropogenic formations. Under the influence of overgrazing, burning out, plowing, their productivity is significantly reduced in comparison with the potential resources of heat, moisture, mineral nutrition, and etc. Under the influence of anthropogenic and technogenic factors, they turned into floristically and cenotically incomplete communities. The species and coenotic incompleteness of pasture ecosystems is expressed in a relatively simplified structural organization, depletion of the botanical composition of the herbage, and low occupancy of plant organs in biohorizons of arid communities [1]. As a result, in such communities, ecological niches remain unrealized for production of the maximum possible amount of organic matter under these conditions. Ecological restoration of degraded pasture ecosystems based on formation of floristically and cenotically full-member, multi-species and multi-tiered shrub-semi-shrub-herbaceous pasture ecosystems with a heterogeneous infrastructure have the most effective architectonics of the assimilative leaf apparatus for photosynthesis and a powerful, deeply penetrating into the soil and the elementary root system for absorption of water nutrition.

The principle of the adaptive strategy of plants and its importance for substantiating the possibility of ecological restoration of degraded pasture ecosystems. If knowledge of the degree of completeness (or rather incompleteness) of natural, degraded pasture ecosystems indicates the possibility and need to recreate them, then the possibility of creating infrastructure-optimized pasture ecosystems is reasonably considered on the basis of knowledge of the following ecosystem principle – types of adaptive plant strategies involved in the community created for the purposes of ecological restoration of degraded pasture ecosystems.

In the process of formation of modern ecosystems, there was a selection of plant species that can exist in an environment that exhibits periodic variability, both in the annual and in the daily cycle, where each species has developed its own special life strategy: a set of adaptations that provide the species with the opportunity to live together with others organisms and occupy a certain position in the corresponding biocenoses [15]. L.G. Ramenskiy [9] identified three types of adaptive strategies in plants: violets, patients, and explents. Similar types of life strategies were identified by G. Grime [10], naming and assigning them the appropriate symbols: competitors (K), stress tolerants (S), ruderals (R).

Violents are species that, while vigorously developing, capture the territory and hold it for themselves, suppressing rivals with the energy of life and full use of the resources of the environment. These include: black saxaul (Haloxylon aphyllum (Minkw). Iljin), Halothamnus subaphyllus ((CAMey.) Botsch.), Wormwood (Artemisia diffusa Krasch.), Bulbous bluegrass (Poa bulbosa L.).

The principle of differentiation of the ecological niche and the mutual complementarity of species and its importance for substantiating the possibility of ecological restoration of pastures. The next important principle of ecological restoration, which is of great methodological and theoretical importance for substantiating the possibility of ecological restoration of degraded pasture ecosystems, is use of the concept of differentiation of ecological niches and mutual complementarity of species. The concept of an ecological niche occupies a central position in modern ecology [15–17]. It arose as an attempt to describe the role of a species in a community, defining all connections between populations, a community, and a given ecosystem.

The concept of an ecological niche explains to a certain extent how different species can function normally and produce, growing side by side with each other, drawing water and mineral resources within a particular ecotope.

According to A.M. Gilyarov [17], the communities are arranged in accordance with the principle of divergence of species in different ecological niches. Their very existence is possible only because their niches differ.

The material presented by us on the ecological restoration of zonally typical basic pasture ecosystems based on formation of shrub-semi-shrub-herbaceous poly-species, multi-level ecosystems in the Central Asian desert fits into the traditional concept of an ecological niche, which provides for the divergence of plant species in the process of successive restoration of biodiversity and forage productivity of degraded zonal ecosystems.

Formed polydominant multi-level pasture ecosystems, which include fodder shrubs, half-shrubs, ephemeral grasses – this is a community of phototrophic plants united according to the principle of maximum use of water resources and elements of mineral nutrition of the soil environment. Cooperative relationships prevail here, providing the participating plants with more favorable living conditions.

In the process of restorative succession in shrub-semi-shrub-herbaceous pasture communities, the differentiation of ecological niches occurs by way of leveled and seasonal complementarity of plant species participating in the restorative succession. The population of black saxaul occupies the upper level, Halothamnus subaphyllus – the second, wormwood – the third, and ephemeroids (bulbous bluegrass) and ephemera – lower layer in multi-species pastures. The layered arrangement of the crown of different life forms of plants in polydominant pasture communities provides formation of an optimal infrastructure for placement of the leaf apparatus of plants for effective photosynthesis. In the underground sphere, various life forms of plants (shrubs, semi-shrubs, ephemeral grasses) form root systems, mastering various ecological niches (soil layers) for the efficient use of water resources and mineral nutrition elements.

Along with the layered complementarity of ecological niches in these shrub-semi-shrub-herbaceous pastures, niches are packed according to the principle of seasonal complementarity of species. These pastures are formed from phenologically different rhythmic plant species: black saxaul, Halothamnus subaphyllus – species with a growing season of 226-242 days. As for the spreading wormwood, it also has a fairly long growing season, but with a summer depression of life processes. Ephemeroid bulbous bluegrass with a short growing season: the beginning of regrowth from February to mid-April, i.e. it uses the resources of the environment, especially the reserves of soil moisture before the start of regrowth of shrubs and semi-shrubs. The growing season at different times ensures the use of environmental resources at different times, in other words, an ecological queue is built up in the use of scarce water and mineral resources of the environment in the desert.

## 5 Conclusion

The studies carried out allow to conclude that the use of zonal typical life forms of dominant species of forage plants and the sowing of their mixtures (combinations) provides the formation of multi-species multi-level pasture ecosystems with a characteristic set of species with high and stable forage productivity over the years in the Central Asian desert. The restored multi-level and multi-species pasture ecosystems are endowed with the property of self-renewal and self-maintenance of the structural and functional organization. The restored multi-species shrub-semi-shrub-herbaceous pasture ecosystems with a characteristic set of species inherent in natural pasture communities are characterized by high stable forage productivity and perform a conservation function in the Central Asian desert.

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