RANGELAND DIVERSITY AS A FORAGE RESOURCE FOR WILD UNGULATES IN THE BARSA KELMES NATURE RESERVE (KAZAKHSTAN)

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Abstract. The nature reserve was founded in 1939 in the limits of the Barsa Kelmes Island (the Aral Sea, Kazakhstan) for the conservation of the saiga antelope (*Saiga tatarica*) and goitered gazelle (*Gazella subgutturosa*). In 1953 kulan from Turkmenistan (*Equus hemionus kulan*) were introduced to the island. The drying up of the Aral Sea led to a junction with the mainland, in the late 1990s. In search of water animals began migrating. For more than 20 years, the rangelands of the former island have not been grazed. A comparative analysis of rangeland productivity between the modern period and the 1970-80s of the last century showed that it has been increased by almost 2 times due to 20 years break of grazing pressure. The natural diet of wild ungulates in the reserve includes 105 species of vascular plants belonging to 26 families and 70 genera. A rangeland map has been compiled based on the interpretation of satellite imagery and field data. The legend to the map contains 16 mapped units. Each mapping unit corresponds to a rangeland type. For each type of rangeland, the total yield is calculated for seasons of the year. The map provides important information for understanding the available forage resources for wild ungulates.
Keywords: *Aral Sea, conservation, mapping, phytomass productivity, desert vegetation*

Introduction

The Barsa Kelmes Nature Reserve in the Aral Sea was established in 1939 to preserve the wild populations of saiga (*Saiga tatarica*, Linnaeus, 1766) and goitered gazelle (*Gazella subgutturosa* Güldendtaedt, 1780). In 1953 the Turkmen kulan (*Equus hemionus kulan*, Boddaort, 1785) was introduced to the island. All of these species are included in the IUCN Red List (IUCN SSC, 2017, 2018; Kaczensky et al., 2020).

The drying up of the Aral Sea led to the fact that in the late 1990s, the territory of the island got connected with the mainland. In search of water sources, the ungulates migrated. In 2006 the former Kaskakulan island and the dry seabed – the territory of the compact habitat of kulans, were added to the reserve. Since then, the total area of the nature reserve increased to 160,826 hectares. There are three artesian wells at the Kaskakulan area, which are important watering sources for animals.

The Barsa Kelmes became the world’s first unique scientific center for the research of flora and fauna and got supported by the reserve staff and scientists for studying the ongoing ecological disaster.

Wild ungulates – saigas, gazelles and kulans are well adapted to the harsh desert conditions of the nature reserve and are the flag ship species of the ecosystem. The plant resources of the deserts are the natural forage source for the occurring wild ungulates.

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When the Barsa Kelmes Nature Reserve was still an island on an area of 186 sq. km, the number of saigas varied sharply from 50 to 2,000 individuals. The number of goitered gazelles in the 70s ranged from 120 to 400 heads. In 1980 more than 200 kulans were observed in the reserve (Eliseev, 2007; Dimeyeva et al., 2012). Since 2021, it has been estimated that there are 690 kulans, 47 saigas, 171 gazelles in the reserve. Basically, the newly added lands to the reserve are subjected to grazing pressure. There is practically no grazing taking place on the territory of the former island Barsa Kelmes. The level of fresh groundwater has dropped due to the drying up of the sea, and the temporary water reservoirs, which appear during spring in the relief depressions dry up by the beginning of summer. Before the catastrophic decline of the Aral Sea, ungulates could also drink brackish sea water.

As the animals migrated from the former island, the grazing pressure has reduced drastically. Currently, kulans no longer graze at the island, and small groups of saigas and gazelles appear on the territory only in the spring, before the temporary water reservoirs dry.

Numerous investigations on biology, ecology and nutrition of saigas, goitered gazelles and kulans have been published in Kazakhstan (Fadeev and Sludsky, 1982; Sludsky et al., 1983; Grachev and Bekenov, 1993; Sokolov and Zhirnov, 1998; Bekenov et al., 1998; Dieterich and Sarsenova, 2012; Shakula and Khabibrakhmanov, 2014; Zhylkaidarov, 2014; Sapanov, 2017; Kaczensky et al., 2017, 2021 and others). In this paper we pay attention only to the fodder resources.

The diet of the saiga has been studied most. The list of plants eaten by saigas includes at least 85 species (Sludskiy, 1955; Sludskiy et al., 1983; Sokolov and Zhirnov, 1998). Plant species diversity within the entire distribution area of saigas varies, so each given population may feed on 40-60 species. The number of forage plants in one season does not exceed 25-35. Of those, only 10-15 plant species are common and may be referred to as the base of saiga diet (Sludsky et al., 1983).

In early spring (March – mid-April), the saigas of Kazakhstan eat at least 11 species of grasses (Minervin, 1955) and do not visit watering places. The most readily eaten cereals are (up to 45%) *Eremopyrum orientale* (L.) Jaub. & Spach, *E. triticeum* (Gaertn.) Nevski, *Poa bulbosa* L., and also *Rheum tataricum* L.f., *Alyssum desertorum* Stapf, *Bassia prostrata* (L.) Beck, *Limonium gmelinii* (Willd.) Kuntze, *L. suffruticosum* (L.) Kuntze.

The basis of food in summer are cereals (*Agropyron fragile* (Roth) P. Candargy, *Eremopyrum* spp., *Bromus tectorum* L., *Festuca amethystina* L., *Poa bulbosa*), and also *Bassia prostrata*, *Salsola laricifolia* Turcz. ex Litv., *Tanacetum achilleifolium* (M. Bieb.) Sch. Bip., *Achillea micrantha* Willd., *Inula britannica* L., *Artemisia* spp., etc.). In Western Kazakhstan, the summer diet of saigas consist of mainly cereals (up to 80%) with the presence of species from other families (*Bassia prostrata*, *Artemisia* spp., *Astragalus* spp., *Glycyrrhiza* spp.). In autumn, when the cereal component of vegetation becomes dry, saigas feed on saltworts and licorice. However, if the cereal species produce a secondary growth in autumn, saiga consumes cereal vegetation with special attention. Autumn plant composition, consumed by saiga, comprises about 20 species, of those saltworts represent the major part. Seeking for the protein, saiga may feed on lichens (Sludsky et al., 1983). In the Volga-Ural interfluve, in autumn saigas feed on annual and perennial saltworts, Artemisia species and *Tanacetum achilleifolium* (Rakov, 1956). In winter, while there is no stable snow cover (December-February), saigas feed on 20 species of plants, and with snow cover – 11 species. In snowless conditions,

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Bassia prostrata, *B. scoparia* (L.) A.J. Scott, *Salsola arbuscula* Pall., *Atriplex tatarica* L., *Anabasis salsa* (Ledeb.) Benth. ex Volkens, *Artemisia austriaca* Jacq., *A. terrae-albae* Krasch., *A. pauciflora* Weber ex Stechm., *A. nitrosa* Weber ex Stechm., *A. lessingiana* Besser are most readily eaten. Periods of high and low abundance of Ural population of saiga alternate depending on the productivity of vegetation communities and territorial humidity (the number of watering places) due to climate change (Sapanov, 2017).

The composition of favorite plants is much less, and they mainly belong to the families Amaranthaceae Juss., Asteraceae Giseke, Brassicaceae Burnett, Rosaceae Juss. Russian scientists (Lebedeva, 1959, 1960; Abaturov et al., 2005; Abaturov and Dzhapova, 2015a) found that this list includes not only species preferred by other herbivorous mammals, but also many other plants (*Lactuca serriola* L., *L. tatarica* (L.) C.A. Mey., *Artemisia austriaca*, *Thlaspi arvense* L.), including poisonous species to other animals (*Descurainia sophia* (L.) Webb ex Prantl, *Anabasis aphylla* L.), which indicates the unpretentiousness of saigas. However high density of poisonous plants from Brassicaceae (*Descurainia sophia*, *Lepidium perfoliatum* L., *Lepidium ruderale* L.) and Liliaceae Juss. family especially on abandoned fields became one of the reasons for the death of the Ural saiga population in 2010-2011 (Dieterich and Sarsenova, 2012). The forage ration of saiga inhabiting Kalmykia (Chernye Zemli Reserve, the saiga population of the northwestern Caspian region) is no more than 25 species, where feather grass dominates in vegetation cover, but its participation in the diet of saiga in all seasons is extremely low, not more than 4% (Larionov, 2008). Studies of Russian population of saiga (Abaturov and Dzhapova, 2015b) showed that the forage diet of saiga requires the participation of forbs. Increasing of the proportion of graminoids and decreasing of forbs in steppe rangelands have a negative impact on the nutrition and state of saigas and does not provide the physiological requirements of the animals.

In different range areas of the saigas, the set of forage plants can change markedly. Adolph (1954) mentioned that in Astrakhan steppe the major component of the diet is *Ephedra distachya* L. and its berries, whereas saltworts (*Salsola* spp., *Anabasis* spp.) and cereals (*Agropyron* spp., *Stipa* spp.) are represented components of secondary importance. It is natural that the saiga has a change of food according to the seasons of the year. Under nature conditions, they are characterized by high mobility and moving from one site to another, selectively use plant food resources, consuming primarily only the most nutritious parts of plants.

Turkmen kulan feeds on as much as 109 plant species (14 species of shrubs, 10 species of semi-shrubs, 40 species of perennial and 45 species of annual grasses) (Solomatin, 1977). Spring diet consists of predominately cereals, and other ephemeral species. Animals avoid consuming dry food in spring season. In the summer animal feeds on predominately cereals and sedges. Autumn diet consists of mainly sagebrush and autumn generation of ephemeral plants. Winter diet is based upon green parts of sedges, cereals, sagebrushes and saltworts. If the snow cover become very high (40 cm and more) kulans switch to shrubs (*Haloxylon* spp., saltworts, *Tamarix* spp., etc.). In Altyn Emel National Park (Shakula and Khabibrakhmanov, 2014) kulan feed on about 110 plant species: in spring time – more than 70 species (cereals, sedges, ephemerals); in summer – 29 species including branches of *Tamarix* spp, *Cousinia* spp.; in winter – up to 31 species (saltworts, sagebrush, *Krascheninnikovia ceratoides* (L.) Gueldenst., *Astragalus* spp.).

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The forage diet of the Turkmen kulan is similar to that of the Mongolian subspecies (*Equus hemionus* Pallas, 1775). Four major vegetation types: mountain steppe (*Agropyron cristatum* (L.) Gaertn., *Stipa krylovii* Roshev.), desert steppe (*Stipa* spp., *Artemisia* spp.), shrub desert (*Haloxylon ammondendron* (C.A. Mey.) Bunge ex Fenzl, *Stipa* spp., halophytes) and oasis (*Phragmites australis* (Cav.) Trin. ex Steud., *Juncus* spp., *Stipa splendens* Trin.) are feeding places of Mongolian Wild Ass (Hilbig, 1990). In the northern Xinjiang, China, kulan feeds 6 species of plants during the year (Chu et al., 2008; Xu et al., 2012a). Amaranthaceae (*Haloxylon persicum* Bunge, *Krascheninnikovia ceratoides*) and Poaceae Barnhart are major food of kulan during spring. *Stipa caucasica* Schmalh. is preferred in spring and summer; shrubs dominated the kulan's natural diet during autumn and winter.

Goitered gazelle has adapted to feeding on a wide variety of plants, it may use lichens, algae, thrown ashore by storms, grasses, forbs, semi-shrubs and shrubs (Sludsky, 1977). In some range areas, up to 70 plant species are included in the diet of gazelle. They often eat plants that are poisonous for livestock – *Peganum harmala* L., *Dodartia orientalis* L., *Zygophyllum* spp. Study of Chinese researchers (Xu et al., 2012b) implemented in Kalamaili Mountain Ungulate Nature Reserve, Xinjiang, showed that goitered gazelles ate 47 species of plants during the year. Amaranthaceae and Poaceae were major foods, and ephemeral plants were used mostly during spring. *Stipa caucasica* was a major food resource of gazelle throughout the year, *Krascheninnikovia ceratoides* was mainly used in spring and summer, whereas in autumn and winter, gazelles consumed large amounts of *Haloxylon ammodendron* branches. During the dry and hot summer and autumn, succulent plants like *Allium polyrhizum* Turcz. ex Regel, *Zygophyllum rosowii* Bunge, *Salsola subcrassa* Popov were favored by gazelles. In winter, the portion of Anabasis, *Stipa splendens* and *Phragmites australis* were evidently higher than in the other seasons.

The forage base of wild ungulates in the Barsa Kelmes Nature Reserve before the catastrophic decline of the Aral Sea was studied by several scientists (Vasenko, 1950; Demchenko, 1950; Rashek, 1974, 1977; Zhevnerov, 1984).

Seasonal preferences of ungulates generally coincide. In spring, they eat ephemerals, especially cereals – *Eremopyrum orientale, Bromus tectorum, Poa bulbosa* and green shoots of wheatgrass and feather grass (*Agropyron fragile, A. desertorum* (Fisch. ex Link) Schult., *Stipa arabica* Trin. & Rupr., *S. caucasica*, *S. lessingiana* Trin. & Rupr.). The most valuable desert cereal is *Eremopyrum orientale*. In spring, in addition to grasses, kulans eat well ephemers (*Chorispora tenella* (Pall.) DC., *Arabis nova* Vill., *Euclidium syriacum* (L.) R. Br.) and seedlings of annual saltworts. In the midst of spring, goitered gazelles well eat *Calligonum* spp., *Atraphaxis spinosa* L., *Caragana grandiflora* (M. Bieb.) DC. Kulans and gazelles also eat young shoots of *Anabasis salsa* and *Artemisia terrae-albae*. In summer *Atriplex tatarica*, *Ceratocarpus arenarius* L., *Alhagi pseudalhagi* (M. Bieb.) Desv. ex B. Keller & Shap. appear in the diet, gazelles eat the fruits of *Nitraria schoberi* L. and *Ephedra disrachya*. By August, cereals dry up and become very coarse and their importance in the forage ration decreases. From that season on, *Anabasis salsa* and species of *Artemisia* play an increasing role. Most ephemerals do not preserve even in the dry state. Biting by kulans such plants as *Crypsis schoenoides* (L.) Lam., *C. alopecuroides* (Piller & Mitterp.) Schrad., *Lepidium latifolium* L., *Girgensohnia oppositiflora* (Pall.) Fenzl, *Amberboa turanica* Iljin, *Halimocnemis sclerosperma* (Pall.) C. A. Mey., *Halimodendron halodendron* (Pall.) Voss is observed only during this period of the year. The main food of gazelle in the

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summer are plants of the Poaceae family (*Agropyron* spp., *Eremopyrum* spp., *Poa bulbosa, Aeluropus littoralis* (Gouan) Parl.), Polygonaceae Juss. (*Atraphaxis spinosa, Calligonum* spp.), Amaranthaceae (*Haloxylon* spp., *Krascheninnikovia ceratoides, Bassia prostrata, Anabasis salsa*), Fabaceae Juss. (*Alhagi pseudalhagi, Caragana grandiflora*). In dry years in the summer, plants of the Asteraceae family (*Artemisia terrae-albae, A. arenaria* DC., *A. quiquiloba* Trautv.) acquire significant importance in nutrition.

In autumn, *Anabasis salsa*, *Frankenia hirsute* L., *Artemisia* spp. are most often eaten, in winter – annual shoots of *Haloxylon ammodendron, H. persicum, Halocnemum strobilaceum* (Pall.) M. Bieb., *Artemisia terrae-albae*, *Anabasis salsa*. Due to saturation of the annual and perennial saltworts with salts, they are eaten by wild ungulates only from the end of September after rains. By the amount of protein *Anabasis salsa, Ceratocarpus arenarius, Haloxylon* spp. surpasses cereals (Kurochkina et al., 1986). Their positive quality is also the relatively small amount of fiber.

In winter after frosts wild ungulates eat *Halocnemum strobilaceum*. In December-January, *Artemisia terrae-albae* dominate in the forage ration of the kulans and saigas, in February – *Anabasis salsa*. In winter as compared to other seasons kulans eat well *Haloxylon* spp. Saigas browses *Ephedra distachya* as well. In periods of heavy snow, gazelles eat large quantities of shrubs and large-stemmed grasses, and in low-snow periods – dwarf semi-shrubs and small shrubs; *Halocnemum strobilaceum, Ephedra disrachya* are the most important among them. *Haloxylon* spp. is especially important during the snowy season.

Forage resources of rangelands vary from year to year and season to season. The study of the productivity of the main plant communities of the Barsa Kelmes Nature Reserve was carried out on ecological sites from 1975 to 1984 during the complex expedition of the Herzen State Pedagogical University of Russia (St. Petersburg). The data of long-term studies were used to assess the forage base of wild ungulates, seasonal dynamics of phytomass accumulation and to determine the average long-term productivity indicators. Yield data of the field research are the basis for compiling maps of forage lands with use of the interpretation of satellite images.

The aim of our research was an inventory of rangeland diversity and mapping of forage resources for wild ungulates in the Barsa Kelmes Nature Reserve.

The following tasks were set to achieve the aim: 1) identification of the species composition of the forage diet of wild ungulates; 2) assessment of rangeland productivity based on field research, retrospective and remote sensing data; 3) development of a rangeland map.

Materials and methods

Study area

The Barsa Kelmes Nature Reserve is located in the northern part of the eastern coast of the former Aral Sea (Kazakhstan) and consists of three cluster areas “Barsa Kelmes”, “Kaskakulan”, including the adjacent territory of the dry seabed, and “Delta”. The research presented in this article is related to cluster area of “Barsa Kelmes” (*Fig. 1*).

The relief of the former island is divided into two parts: the southern – high plateau and the northern – undulating plain crossing from south to north by valleys of temporary streams (Kuznetsov, 1979). The highest point (108 m asl) is located at the western coast (Butakov cape). The northwestern, northern and eastern coasts are bordered by belt of sand dunes which are the old Aral marine terraces. The primary marine plain is formed on the dry seafloor with a slightly inclined surface (Dimeyeva et al., 2012).

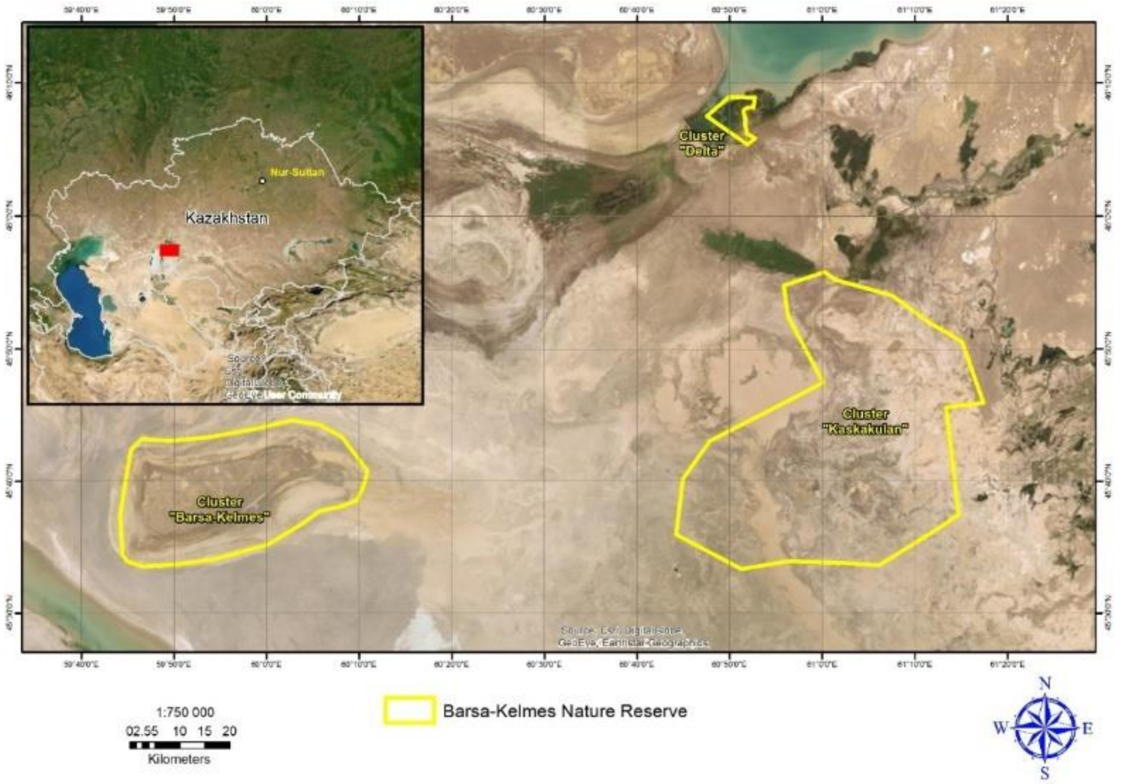

Figure 1. *Study area*

The climate is temperate with long hot summers, relatively cold winters, and low precipitation that is typical for the temperate deserts of Turan lowland. The average annual precipitation is low (126–128 mm). The average air temperature in July is 25–26 °C; the absolute maximum reaches 42–44 °C. The average air temperature in January is –10–13 °C; the absolute minimum is –34–36 °C with strong winds (the maximum reaches 20–24 m/s) (Dimeyeva et al., 2012).

The light brown desert soils (Calcic Xerosols) of different salinity and texture are represented at the original coast of the former island (Erokhina, 2016). There are also takyrs, salt marshes and sandy soils. Within the dry seabed different types of solonchaks are distributed (gleyic, gaplic, degraded, takyr-like), and coastal saline sands.

Vascular flora of the Barsa Kelmes cluster area consists of 264 species, belonging to 42 families and 164 genera. These data are obtained from published papers (Dimeyeva, Alimbetova, 2007; Dimeyeva et al., 2012) taking into account the latest field research data of 2019. Species from Amaranthaceae (49), Asteraceae (32), Brassicaceae (26), Poaceae (27), Polygonaceae (21) families prevail. The most important genera are Calligonum (15), Artemisia (10), Atriplex (7), and Salsola (6).

Zonal vegetation is composed by *Artemisia terrae-albae* and *Anabasis salsa* with sparse *Haloxylon ammodendron*. The intrazonal vegetation is distributed on solonchaks with *Halocnemum strobilaceum* and *Limonium suffruticosum* communities. Saltwort

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vegetation covers takyr-like solonchaks (*Climacoptera aralensis* (Iljin) Botsch., *C. brachiate* (Pall.) Botsch., *Salsola foliosa* (L.) Schrad. ex Schult., *Halimocnemis sclerosperma*). Communities of *Haloxylon ammodendron*, *H. persicum* dominate in hummocky sand dunes. Plant communities with share of *Atraphaxis spinosa*, *Ephedra distachya*, *Calligonum* spp, *Convolvulus erinaceus* Ledeb. are less significant. Vegetation of the dry seafloor is characterized by a belt distribution parallel to the coastline. Aggregations of *Salicornia europaea* L., *Tamarix hispida* Willd., *Bassia crassifolia* (Pall.) Soldano, *Suaeda acuminata* (C.A. Mey.) Moq., *Halocnemum strobilaceum* are common on coastal salt marshes. The desalinization of the sand and the deflation of surface horizons lead to the formation of psammophytic communities of *Stipagrostis pennata* (Trin.) de Winter, *Eremosparton aphyllum* (Pall.) Fisch. & C.A. Mey, *Astragalus brachypus* Schrenk. The former island Barsa Kelmes is joined to the original eastern coast before 2000s. Vegetation cover between the island and the original coast consists of aggregations of annual saltworts (*Atriplex pratovii* Sukhor., *Bassia hyssopifolia* (Pall.) Kuntze, *Salsola nitraria* Pall.) with *Tamarix laxa* Willd., *Nitraria schoberi*. Lands with a rare plant cover or without plants frequently occur.

Field research was implemented in early June 2019 with the participation of the nature reserve staff. The objects of investigation were plant communities representing desert rangelands. Sites for productivity estimations were defined in areas with typical vegetation cover.

Methods

The vegetation was studied using traditional methods of geobotanic field research, including the geobotanical description of the main vegetation communities and the landscape and ecological profiling with the use of topographic maps and satellite imagery (Bykov, 1957, 1978; Tueller, 1988). Occasionally, geolocation was registered by a GPS device, and the detailed geobotanical description was compiled of the main plant communities representative for the area.

Geobotanical description

For each plant community, coordinates, landscapes, soils, water regime, total projective coverage, layers, degree of transformation were defined; the full floristic composition was given, phenological phases of plant species, vigour (according to a 5-point scale), abundance (by Drude scale), spreading (by Bykov’s scale), morphometric parameters (height, habitus) were defined. Description of vegetation is carried out at the vegetation description form. The herbarium was collected. The identification of species was carried out in the office period on the basis of identification keys of 9-volume “Flora of Kazakhstan” (1956-1966) and 2-volume “Illustrated Guide for Identification of the Plants of Kazakhstan” (1969, 1972). The names of plant species, genera, and families were quoted in accordance with summaries by the APG IV system (Chase et al., 2016) and Internet resource of The World Flora Online.

Estimating the amount of standing crop of plant material (economic productivity)

Methods for determining the productivity of pastures are described by Brown (1954), Ramensky et al. (1956), Nechaeva (1957), Bykov (1978), Kurochkina et al. (1986), Ospanov (1995), Smith et al. (2012), etc. The account of yield is made by two basic methods: clipping (usually on square plots) and model bushes (on transects).

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Method of clipping (harvest method)

This method involves clipping all the above-ground plant material (standing crop – either current year's growth or total) in a quadrat and weighing it. To determine the standing crop use metal frames (quadrats) of 0.25 sq. m. They were located objectively and preferably with randomization in 12 - fold repetition (3 sq. m). Clipping of plants was carried out separately by species or by economic groups: unpalatable plants (poisonous, weed), ephemerals, herbs (tall grass, legumes, etc.), wormwood/sagebrush (well eaten, poorly eaten) and saltworts (annual, perennial). An approximate percentage of the phytomass eaten on the grazed grass stands is set, after that corrections are made for a certain yield. On desert low grass rangelands, the phytomass is clipped at a height of 1 cm from the soil surface. On semi-shrub and shrub rangelands only young leaves and shoots (annual growth) were cut. The phytomass samples are weighed in the field immediately after clipping, then it is dried to an air-dry basis.

Method of model bushes

It is used to determine the productivity of shrub and semi-shrub vegetation. The method lays transect on which all species are calculated, except for seedlings. The calculation was carried out taking into account the size of plants, which are grouped in 2-3 groups with similar height and diameter. On the transect all specimens were counted in three categories: large, medium, and small. Model plants of each size were selected and annual growth cut off. The yield of bushes of shoots' type was defined by 1 m × 1 m or 2 m × 2 m quadrats (depending on plant height) in 2-fold repetition. All the yield data were recorded in the vegetation description forms, the yields were converted to centners or kilograms per hectare.

Field mapping

Rangeland vegetation mapping was carried out by a combination of detailed-route research and the method of landscape-ecological profiling using the topographic maps and satellite images (Sochava, 1979; Berlyant, 1997). At geolocations defined on the ground by the GPS device, a detailed geobotanical description of the main, predominant in area, plant communities were carried out. Cartographic materials (digital layers of the topographical map, satellite imagery) are reorganized within an ArcGIS software interfaced database.

Remote sensing methods

Remotely sensed data were used to calculate major biophysical parameters of pastures, such as grass cover percentage and biomass production. Satellite data from Landsat OLI sensor (path 160-161 row 028) were obtained from https://earthexplorer.usgs.gov. Satellite imagery acquired covers the period from early summer till early autumn of 2019 to provide an adequate understanding of the vegetation dynamics for the year of 2019:

6 June 2019 (LC08_L1TP_160028_20180614_20180703)
8 June 2019 (LC08_L1TP_161028_20190608_20190608)
17 June 2019 (LC08_L1TP_160028_20190617_20190620)
20 August 2019 (LC08_L1TP_160028_20190820_20190903)
27 August 2019 (LC08_L1TP_161028_20190827_20190827)
12 September 2019 (LC08_L1TP_161028_20190912_20190917)

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Satellite images were pre-processed with Excelis ENVI 5.3, the pre-processing procedure included the radiometric calibration of raw satellite data and the atmospheric correction of calibrated scenes. We used Excelis ENVI 5.3 to calculate spectral indices, further used to develop map products.

Indices, calculated with satellite data were processed along with ground data to define the better correlations of satellite and ground information. We used Statsoft STATISTICA 12.0 to perform this part of the entire workflow.

We further used ArcGIS 10.5 to process raster data and to visualize resulting maps.

The selection of spectral indices is based upon the previous studies of the spectral parameters and vegetation cover in the desert areas of Kazakhstan (Malakhov and Islamgulova, 2014, 2015). *Table 1* enlists major indices, used in this paper along with meaningful range of the given index values.

Table 1. *Spectral indices, used in current study*

Index	Expression	Range	Designation
Salinity index	$\sqrt{\frac{blue}{red}}$	> 0.23	Outlining of superficial soil salinization
Water index	$\frac{green-nir}{green+nir}$	> 0.1	Outlining of water bodies
Top soil grain size	$(red-blue)*(red+blue+green)$	0.01-0.025	Differentiation of gravel, sand and clay
Water concentration in green biomass (NDWI)	$\frac{nir-swir}{nir+swir}$	> 0	Calculation of green biomass
Bare soil index	$(\frac{nir-green+red}{nir+green+red})*(-1)$	Vary for different soil types	Delineation of areas with depleted or vanished vegetation cover

blue – blue band of satellite image, spectral range 450-520 nm; green – green band of satellite image, spectral range 530-600 nm; red – red band of satellite image, spectral range 630-680 nm; nir – near infrared band of satellite image, spectral range 850-890 nm; swir – short-wave infrared band of satellite image, spectral range 1570-2290 nm

Calculation of green biomass by satellite data

Vegetation Water Content is an important tool for estimating biophysical vegetation parameters (Penuelas et al., 1993). Shortwave infrared reflectance (SWIR) is negatively correlated to the leaf-water content due to the large absorption of water by the leaf (Yilmaz et al., 2008). Gao (1995) proposed a following narrow-band index, describing the water concentration in green biomass, as a tool for estimating vegetation status (*Eq. 1*):

$$NDWI = \frac{(\rho_{857} - \rho_{1241})}{(\rho_{857} + \rho_{1241})} \quad \text{(Eq.1)}$$

where *ρ857* and *ρ1241* represent the reflectance value in the corresponding band of the satellite image.

It is noticeable that the index operates with the infrared spectrum, only, unlike NIR-RED-based indices. The application of NDWI (Normalized Difference Water Index)

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and the high value of its correlations with biophysical vegetation variables explains the physiology of different types of desert vegetation in a better way than NIR-RED-based vegetation indices. The idea of this index is based on the fact, that “Liquid water absorption in the 1.5-2.5 μm region (short-wave infrared, SWIR) for green vegetation is significantly stronger than that of the 0.9-1.3 μm (near infrared, NIR) region” (Gao, 1995).

The index of water concentration in vegetation (NDWI) demonstrated the stable correlation to vegetation cover parameters. Pearson coefficients ($p < 0.05$) are respectively as following 0.78, 0.76 and 0.73 for grass cover, green biomass and productivity.

Seasonal biomass of the Barsa Kelmes pastures was calculated on Landsat data using NDWI and seasonal correction coefficients proposed by Lebed (1989). Production (mass of dry matter) is closely related to green vegetation mass (Malakhov and Islamgulova, 2014), and could be easily estimated from biomass values taken from satellite data.

Results

Forage ration of wild ungulates in the Barsa Kelmes cluster area

The list of forage plants of wild ungulates (*Table A1* in the *Appendix*) has been compiled on a basis of previous publications (Vasenko, 1950; Demchenko, 1950; Rashek, 1974, 1977; Zhevnerov, 1984). It was important for us to compare which species from the local flora of the Barsa Kelmes cluster area are eaten by ungulates, what is common and what are the differences.

The general list of plants eaten by wild ungulates consists of 105 species belonging to 26 families and 70 genera, which is about 40% of the local flora. Among them 35 species are eaten by saigas, 78 – by gazelles, and 71 – by kulans. The preferences of ungulates are similar. In the first place are the Poaceae family, in the second – the species of the Amaranthaceae family, in the third place in the saiga and gazelle ration – Asteraceae, and in the kulan’s ration – Brassicaceae; Fabaceae and Poligonaceae are in fourth and fifth places. 26 species (25% of forage plants) are eaten by all wild ungulates of the reserve (saiga, gazelle, kulan).

Analysis of retrospective studies on productivity dynamics of plant communities in the Barsa Kelmes cluster area

From the beginning of the 70s to the end of the 80s of the last century, students and teachers of the Department of Botany of Herzen University conducted research on the productivity of forage plants of the Barsa Kelmes Island. Only one article was published based on research materials (Romanova et al., 1979). MS theses of students were used for a comparative analysis, which present the results of long-term field observations on the Barsa Kelmes Nature Reserve (Perchatkina, 1979; Galieva, 1980; Kukhtenko, 1989). The studies were carried out on phenoclimatic seasons (Kuznetsov and Burambaev, 1976): early spring (3 decade of March – 1 decade of April, stable temperature transition through 0 °C); full spring (2-3 decade of April – 1 decade of May, the transition of average daily temperatures through +5 °C); early summer (2-3 decades of May – 1-2 decades of June, the transition of average daily temperatures

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through +15 °C); hot summer (3 decade of June – July, average daily temperature is above +22-23 °C); late summer (August, September).

Dynamics of the yield of the Anabasis salsa – Artemisia terrae-albae complex

The vegetation cover of zonal ecosystems is dominated by complexity, where the components are *Artemisia terrae-albae* and *Anabasis salsa* communities, which regularly alternate depending on the microrelief and soil salinity. The ratio of the elements of the complex depends on the position in the landscape. In the undulating plains, the *Artemisia terrae-albae* communities account for about 60% of the area. The rest is occupied by the *Anabasis salsa* communities (Kuznetsov, 2007).

The analysis of regularities of productivity is based on the MS thesis (Galieva, 1980), which discusses the data of 1976-1979. The study of yield was carried out on ecological sites representing the phytocoenotic diversity of the complex within the plain.

Plots (plant communities, i.e. com.) in the central part of the island:

(I-1) *Artemisia terrae-albae – Agropyron desertorum* com.
(I-2) *Artemisia terrae-albae* com.
(I-3) *Anabasis salsa – Artemisia terrae-albae* com.
(I-4) *Anabasis salsa* com.
(II-1) *Anabasis salsa* com.
(II-2) *Anabasis salsa – Artemisia terrae-albae* com.

Plots in the western part of the island:

(V-1) *Artemisia terrae-albae* com. in a plane
(V-2) *Anabasis salsa* com.
(V-3) *Artemisia terrae-albae* com. in a slope
(V-4) *Artemisia terrae-albae – Stipa lessingiana – Agropyron desertorum* com. in a ravine

The results of long-term research were carried out for all plots, for some of them which representing the diversity of zonal communities we present diagrams to illustrate the dynamics of the yield (*Figs. 2-5*).

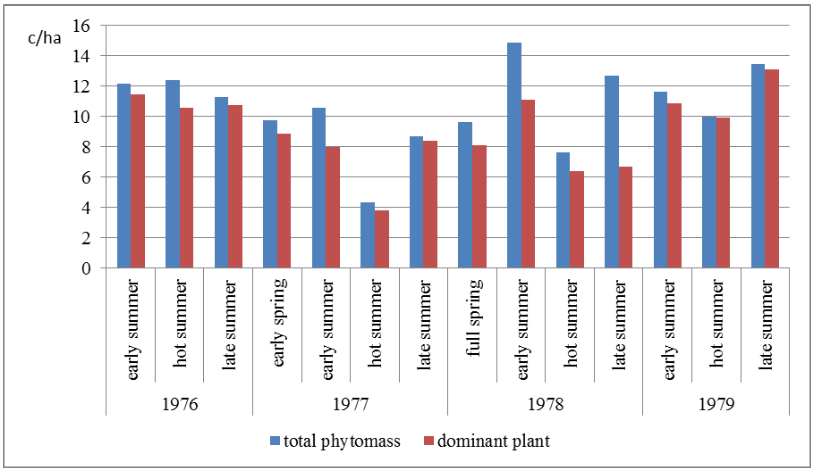

Figure 2. *Productivity dynamics of Artemisia terrae-albae – Agropyron desertorum com. (I-1)*

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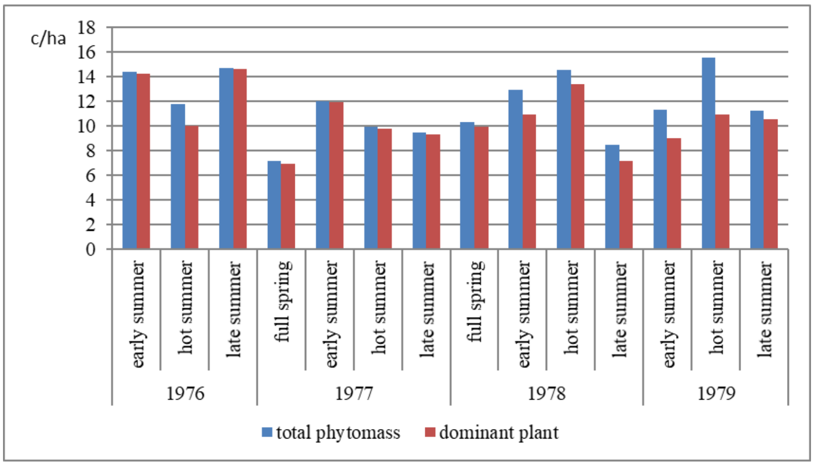

Figure 3. *Productivity dynamics of Artemisia terrae-albae com. (I-2)*

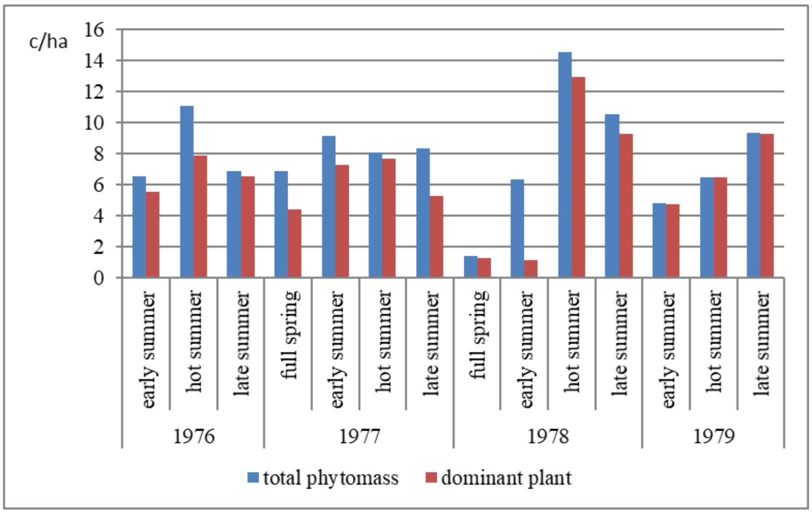

Figure 4. *Productivity dynamics of Anabasis salsa com. (I-4)*

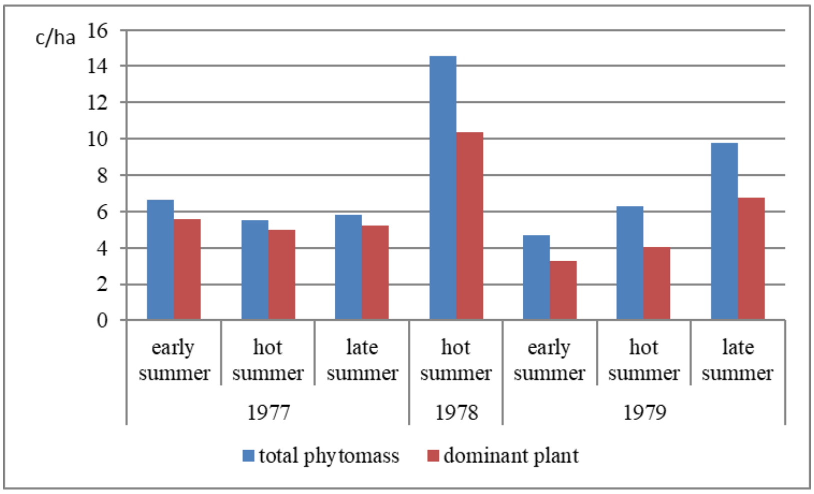

Figure 5. *Productivity dynamics of Artemisia terrae-albae – Stipa lessingiana – Agropyron desertorum com. (V-4)*

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Based on long-term studies it was found that the *Artemisia terrae-albae* communities play a significant role in a complex vegetation, which accumulates on average 11.3 centners per hectare (c/ha) of phytomass during the spring and summer periods. The smaller yield falls on the share of *Anabasis salsa* communities – 7.4 c/ha.

The dynamics of yield in *Artemisia terrae-albae* varies widely in phenoclimatic seasons; the maximum yield is formed more often in early summer and in hot summer. In communities with the participation of subdominants, the seasonal yield is different. In *Artemisia terrae-albae – Agropyton desertorum* com. (I-1), the accumulation of the maximum phytomass is mostly confined to the beginning of summer; *Artemisia terrae-albae – Stipa lessingiana – Agropyron desertorum* com. (V-4) productivity varies from season to season. In *Anabasis salsa* com. (I-4) the development of the maximum yield is noted during the hot summer season, although there may be seasonal fluctuations. In addition, the yield of annual saltworts (*Climacopteraa aralensis, Halimocnemis sclerosperma, Salsola foliosa*) and perennial saltworts (*Halocnemum strobilaceum*) was determined, which are characterized by high phytomass (from 35.6 to 44.6 c/ha).

An assessment of changes in yield was made depending on the grazing of wild ungulates. For this, plots were defined on the grazed area and within the boundaries of protective fence (*Table 2*). The yield of ungrazed *Artemisia terrae-albae* com. higher than grazed by 1.3-2 times. In the communities of *Agropyron desertorum* at the beginning of summer, the yield of plots practically does not differ, and in a hot summer in the grazed area it decreases by 2.6 times. In *Anabasis salsa* com. on the grazed area, the phytomass is by 2-2.7 times higher. Average long-term indicators of seasonal yield are presented in *Table 2*, which was later used in the development of a rangeland map.

Table 2. *Average indicators of the productivity of communities in Anabasis salsa – Artemisia terrae-albae complex*

Plant communities/plots	Average yield, c/ha				
	Spring	Early summer		Summer	
Artemisia terrae-albae - Agropyron desertorum com. (I-1)	9.7	12.4		10.8	
Artemisia terrae-albae com. (I-2)	9.1	12.6		12.5	
Anabasis salsa – Artemisia terrae-albae com. (I-3)	6.4	8.4		8.2	
Anabasis salsa com. (I-4)	4.1	6.7		8.5	
Anabasis salsa com. (II-1)	4.1	4.8		7.1	
Anabasis salsa – Artemisia terrae-albae com. (II-2)	3.3	5.2		6.6	
Artemisia terrae-albae com. (V-1)		7.8		11.9	
Anabasis salsa com. (V-2)		9.5		9.2	
Artemisia terrae-albae com. (V-3)		13.9		15.2	
Artemisia terrae-albae – Stipa lessingiana – Agropyron desertorum com. (V-4)		5.7		7.6	
Halimocnemis sclerosperma com.				44.5	
Annual saltwort com. (*Salsola foliosa, Climacoptera aralensis*)				30.3	
		In the fence	**Behind the fence**	**In the fence**	**Behind the fence**
Artemisia terrae-albae com.		26.5	19.9	26.6	13.8
Anabasis salsa com.		5.1	13.6	5.6	10.9
Agropyron desertorum com.		3.6	3.8	3.9	1.5

Dynamics of the yield of sandy desert vegetation

A sand belt in the island is confined to the old Aral marine terraces, the origin of which is associated with transgressions and regressions of the sea level. The vegetation

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cover is dominated by: *Haloxylon ammodendron, H. persicum, Atraphaxis spinosa, Ephedra distachya, Calligonum aphyllum* (Pall.) Guerke, *C. caput-medusae* Schrenk, *C. macrocarpum* I.G. Borshch., *C. acanthopterum* I.G. Borshch. From the sea side, the Aral terrace is adjoined by a strip of dunes, which represent a coastal rampart of 1.5-3 m high. The vegetation of the dune is formed by tamarisk (*Tamarix laxa, T. ramosissima* Ledeb., *T. hispida), Haloxylon ammodendron, Calligonum* spp. The analysis of the patterns was carried out on the basis of the MS thesis (Perchatkina, 1979). The study was carried out in 1976-1978 on two ecological sites.

Site IX is located on the northern coast. The productivity of the aboveground phytomass of the following communities were studied:

(IX-1) Psammophitic shrub (*Calligonum aphyllum, Atraphaxis spinosa)* with *Tamarix laxa* and *Haloxylon ammodendron* com.
(IX-2) *Aeluropus littoralis* com.
(IX-3) *Ephedra distachya* com. of dense coverage
(IX-4) *Ephedra distachya* com. of sparse coverage

Site X is located at the eastern coast. The following communities were studied:

(X-1) *Haloxylon* spp. with *Calligonum aphyllum, Tamarix laxa* com.
(X-2*) Ephedra distachya – Haloxylon persicum* com.
(X-3) *Ephedra distachya – Calligonum aphyllum* com.
(X-5) *Stipagrostis pennata* com. on hummocks
(X-5a) *Stipagrostis pennata* com. in a beach

In the psammophytic shrub with *Tamarix laxa* and *Haloxylon ammodendron* com. (IX-1) the largest part in the total yield is formed by tamarisk; psammophytic shrubs (*Atraphaxis spinosa, Calligonum aphyllum*) and *Haloxylon ammodendron* compose from 5 to 24% of the total phytomass. The highest yield (54.9 c/ha) was formed in the late summer in 1978, and in 1976-1977 the maximum was in early summer (*Fig. 6*).

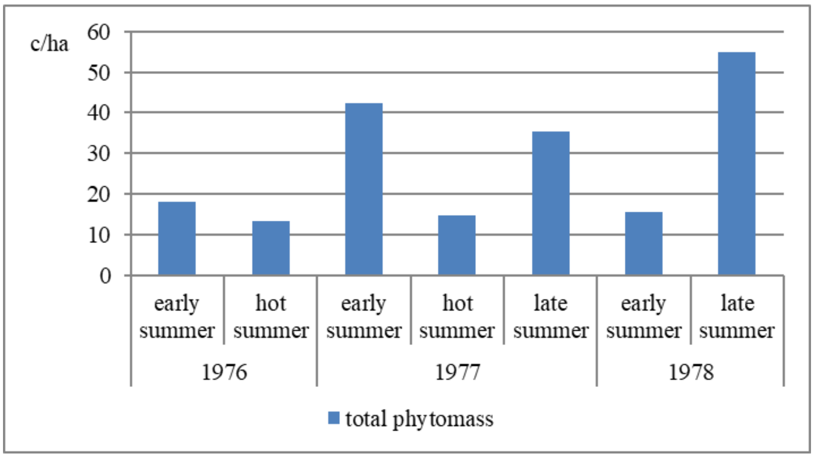

Figure 6. *Productivity dynamics of psammophytic shrub with Tamarix laxa and Haloxylon ammodendron com. (IX-1)*

The maximum phytomass of the *Aeluropus littoralis* (IX-2) community accumulates at the early summer (36.9 c/ha in 1977), during the hot summer it is minimal (3.0 c/ha in 1977). The highest phytomass in dense ephedra com. (IX-3) was observed at the

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early summer in 1977 (62.6 c/ha), which was also due to a large number of ephemerals. In sparse ephedra com. (IX-4), the maximum yield was noted in the full spring of 1977 (62.9 c/ha), ephemerals accounted for 15% of the total phytomass, during the hot summer the aboveground phytomass was minimal (2.3 c/ha).

In the community of *Haloxylon* spp. with *Calligonum aphyllum* and *Tamarix laxa* com. (X-1), formation of the maximum phytomass is confined to the hot and late summer seasons. The highest productivity of shrubs was in 1977 (67.4 c/ha).

Yield fluctuations of *Ephedra distachya – Haloxylon persicum* com. (X-2) are shown in *Figure 7*. The maximum phytomass was formed at the full spring of 1977 (13.6 c/ha); in other years its accumulation was confined to the early and hot summer seasons.

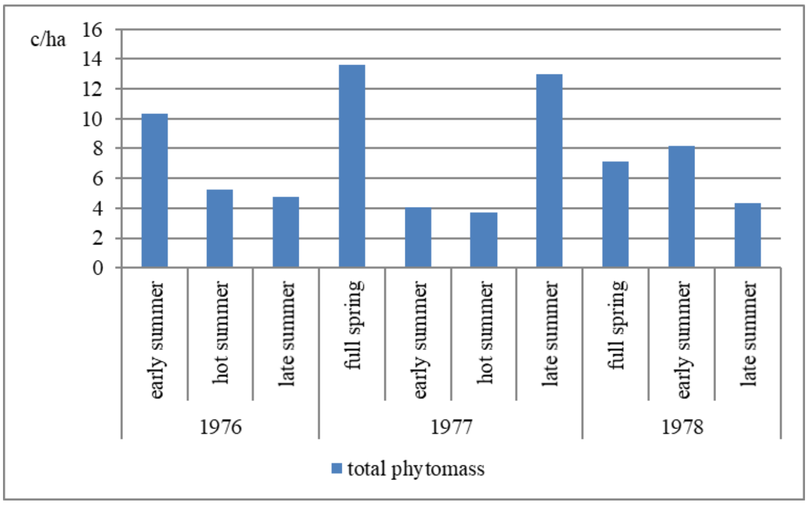

Figure 7. *Productivity dynamics of Ephedra distachya – Haloxylon persicum com. (X-2)*

Average long-term indicators of seasonal productivity are presented in *Table 3*, which were used to develop the rangeland map.

Table 3. *Average indicators on productivity of sandy desert communities*

Plant communities/plots	Average yield, c/ha	
	Spring	**Summer**
Psammophytic shrub with *Tamarix laxa* and *Haloxylon ammodendron* com. (IX-1)	15.6	30.1
Atraphaxis	0.1	0.1
Calligonum	0.6	0.9
Haloxylon	0.2	0.2
Tamarix	14.7	28.9
Aeluropus littoralis com. (IX-2)	5.3	4.8
Ephedra distachya coms. (IX-3,4)	26.6	17.6
Haloxylon spp. with *Calligonum aphyllum, Tamarix laxa* com. (X-1)	0.5	34.7
Haloxylon	0.3	7.4
Calligonum	0.2	1.3
Tamarix	-	26.0
Ephedra distachya - Haloxylon persicum com. (X-2)	10.4	5.4
Ephedra distachya – Calligonum aphyllum com. (X-3)	16.4	8.3
Stipagrostis pennata coms. (X-5, 5a)	0.7	4.2

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Additional information on productivity of psammophytic vegetation was provided in the MS thesis of Kukhtenko (1989). The work analyzed 10-year data on the dynamics of productivity in the summer (3 phenoclimatic seasons). Six plant communities were selected for the study:

Haloxylon ammodendron – Calligonum aphyllum – Ephedra distachya com.
Haloxylon spp. – *Ephedra distachya* com.
Calligonum aphyllum – Epherda distachya com.
Shrub (*Tamarix laxa, Haloxylon spp., Calligonum aphyllum*) com.
Stipagrostis pennata com.
Atraphaxis spinosa – Aeluropus littoralis com.

Long-term dynamics of productivity for some communities are shown in the graphs (*Figs. 8-9*).

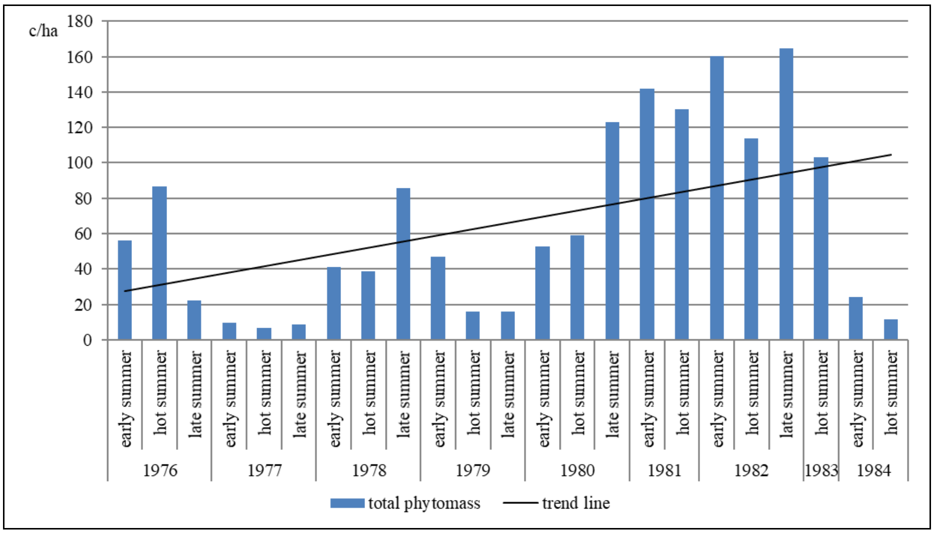

Figure 8. *Productivity dynamics of Haloxylon ammodendron – Calligonum aphyllum – Ephedra distachya com.*

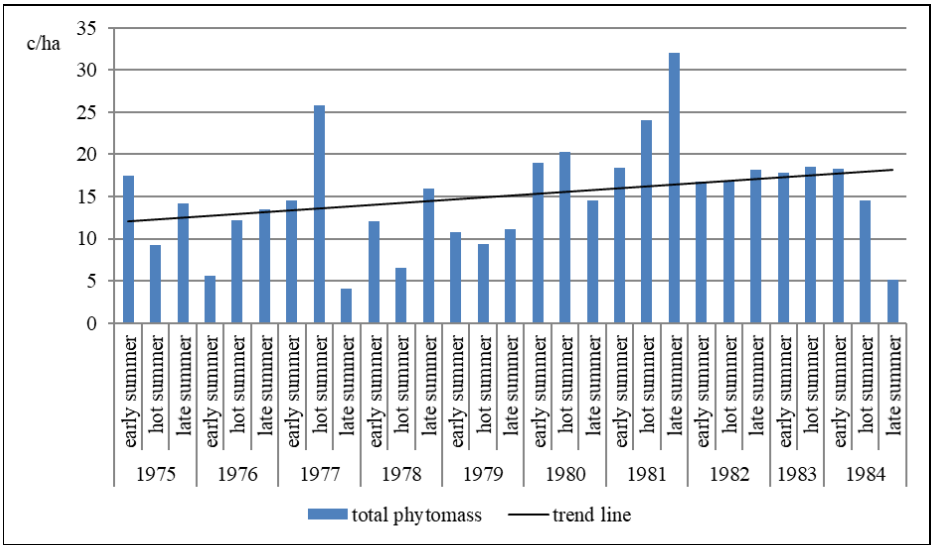

Figure 9. *Productivity dynamics of Haloxylon spp. – Ephedra distachya com.*

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On the basis of the study, the average indicators for the summer period in long-term dynamics were calculated; the communities are located as the yield decreases: 1) *Haloxylon ammodendron – Calligonum aphyllum – Ephedra distachya* com. – 66.1 c/ha; 2) shrub (*Tamarix laxa*, *Haloxylon spp.*, *Calligonum aphyllum*) com. – 50.9 c/ha; 3) *Haloxylon* spp. – *Ephedra distachya* com. – 15.1 c/ha; 4) *Calligonum aphyllum – Ephedra distachya* com. – 13.9 c/ha; 5) *Atraphaxis spinosa – Aeluropus littoralis* com. – 8.2 c/ha; 6) *Stipagrostis pennata* com. – 5.4 c/ha.

The current state of forage resources in the Barsa Kelmes cluster area

Assessment of phytomass accumulation by traditional methods

The study of the accumulation of forage mass was carried out in the first ten days of June 2019 (early summer). The yield was determined by the methods of clipping and model bushes. The sequence of determining the stocks of forage mass included several stages: laying of standard plots (quadrats) or choosing model bushes; clipping off the forage mass; weighing raw phytomass, drying, weighing air dry phytomass; recalculation of the obtained data into centners per hectare. The results are shown in *Table 4.*

Table 4. *Yield of forage mass of the Barsa-Kelmes reserve plant communities*

Coordinates	Plant community	Coverage %	Number (area) of shrubs per ha	Species	Wet weight, centner per ha	Air dry weight, centner per ha
45°40′56′′ N 60°10′13′′ E	*Kalidium foliatum* (Pall.) Moq.	15-20		Kalidium	18.0	4.3
45°41′59′′ N 60°08′07′′ E	*Haloxylon ammodendron – Astragalus brachypus*	30	1650	Haloxylon	7.1	2.8
			711	Astragalus	0.7	0.2
				Total:	7.8	3.0
45°42′06′′ N 60°07′31′′ E	Sparse *Haloxylon ammodendron* with *Nitraria schoberi*	15	4400 sq.m	Nitraria	12.1	3.7
45°42′26′′ N 60°05′33′′ E	*Halocnemum strobilaceum*	15-20		Halocnemum	21.0	5.9
45°42′30′′ N 60°05′20′′ E	*Atraphaxis spinosa*	20	3100	Atraphaxis	5.3	3.0
45°42′02′′ N 60°04′57′′ E	Sparse *Ephedra dystachya*	5-10	1300 sq.m	Ephedra	1.5	0.6
45°42′05′′ N 60°04′26′′ E	*Haloxylon ammodendron – Calligonum aphyllum- Ephedra distachya* with *Tamarix laxa*	40	4400	Haloxylon	52.4	15.7
45°40′29′′ N 59°54′11′′ E	Complex of *Anabasis salsa* (70%) and *Artemisia terrae-albae* (30%) communities	45-50		Anabasis com.:		
				Anabasis	29.0	14.5
				Saltworts	7.2	2.7
				Ephemerals	1.2	0.5
				Total:	37.4	17.7
		60		Artemisia com.:	37.5	23.0
				Average for the complex:	37.5	20.4
45°40′39′′ N 59°54′44′′ E	Annual saltwort	15-20		Saltworts	16.3	3.3
45°40′39′′ N 59°54′44′′ E	Psammophytic shrub with single *Haloxylon ammodendron*		1600	Calligonum	7.6	1.9
45°38′00′′ N 59°47′00′′ E	*Anabasis salsa* with saltworts and single *Haloxylon ammodendron*	50		Anabasis Ceratocarpus Saltworts Total:	48.7 1.3 2.0 52.0	20.4 0.9 0.5 21.8

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45°37´24´´ N 59°47´12´´ E	*Artemisia terrae-albae* with single *Anabasis aphylla*	50		Artemisia Ceratocarpus Ephemerals Total:	26.0 1.0 0.3 27.3	16.5 1.0 0.3 17.8
45°42´212´´ N 60°03´05´´ E	*Artemisia terrae-albae* (60%) with microcoenoses of *Agropyron fragile*, *Stipa lessingiana* (10%) and single *Haloxylon ammodendron*	70		Artemisia Agropyron Stipa Ceratocarpus Ephedra Total:	6.0 10.3 3.8 2.3 0.8 23.2	3.8 6.2 2.2 2.3 0.3 14.8
45°41´45´´ N 59°58´60´´ E	*Calligonum acanthopterum-Ammodendron conollyi* Boiss. with *Artemisia quinqueloba*	50	700 800	Artemisia Calligonum Total:	1.1 3.6 4.7	0.4 1.0 1.4
45°41´11´´ N 60°02´40´´ E	Grass (*Stipa lessingiana*, *Agropyron desertorum*) with *Ephedra distachya*, *Rhaponticum repens* (L.) Hidalgo	90		Grass Ephedra Rhaponticum Total:	15.0 1.2 0.5 16.7	9.6 0.3 0.1 10.0
45°41´33´´ N 59°58´40´´ E	*Tamarix laxa*	60-70	1600	Tamarix	10.6	4.2

Assessment of forage mass accumulation by remote sensing methods

Landsat OLI images were used to calculate seasonal yield.

The temporal coverage (early summer - mid-autumn) of these data allowed reliably assessing the dynamics of soil-vegetation cover and calculating the main seasonal biophysical parameters of rangelands (biomass and dry weight). The use of the author's methodology (Malakhov and Islamgulova, 2014, 2015) and seasonal correction factors (Lebed, 1989) allowed to compile a series of maps of rangeland productivity in the Barsa Kelmes Nature Reserve for different seasons (*Fig. 10*).

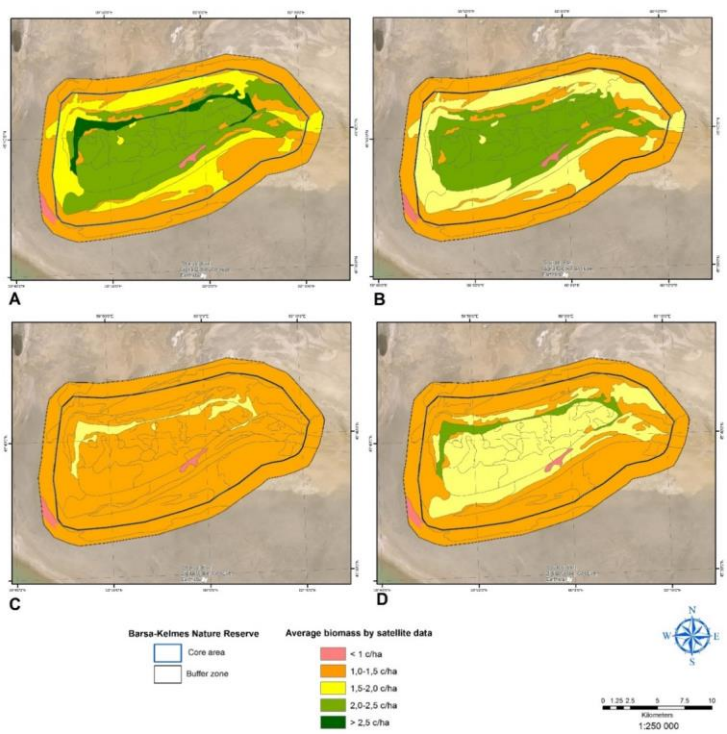

Figure 10. *Yield of rangelands for different seasons: A – spring, B – summer, C – autumn, D – winter*

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Rangeland map of the Barsa Kelmes cluster area

The stages of the rangeland map (*Fig. 11*) compilation included: systematization of geobotanical descriptions, interpretation of the Landsat OLI satellite image, drawing up a contour map, and developing a legend for the map. The available cartographic materials were analyzed to create the map: Map of forage lands of Kazakhstan (Scale 1:2 000 000) (Bakanach et al., 1978); Vegetation map of Kazakhstan and Central Asia (within the limits of desert zone) (Scale 1:2 500 000) (Rachkovskaya, 1995); Vegetation map of Kyzylorda region (Scale 1:1 500 000) (Dimeyeva, 2020); Map of soils (Scale 1:1 350 000) (Erokhina, 2016); Map of vegetation (Scale 1:1 350 000) (Rachkovskaya and Egemberdieva, 2016), and some archive materials of the Barsa Kelmes Nature Reserve.

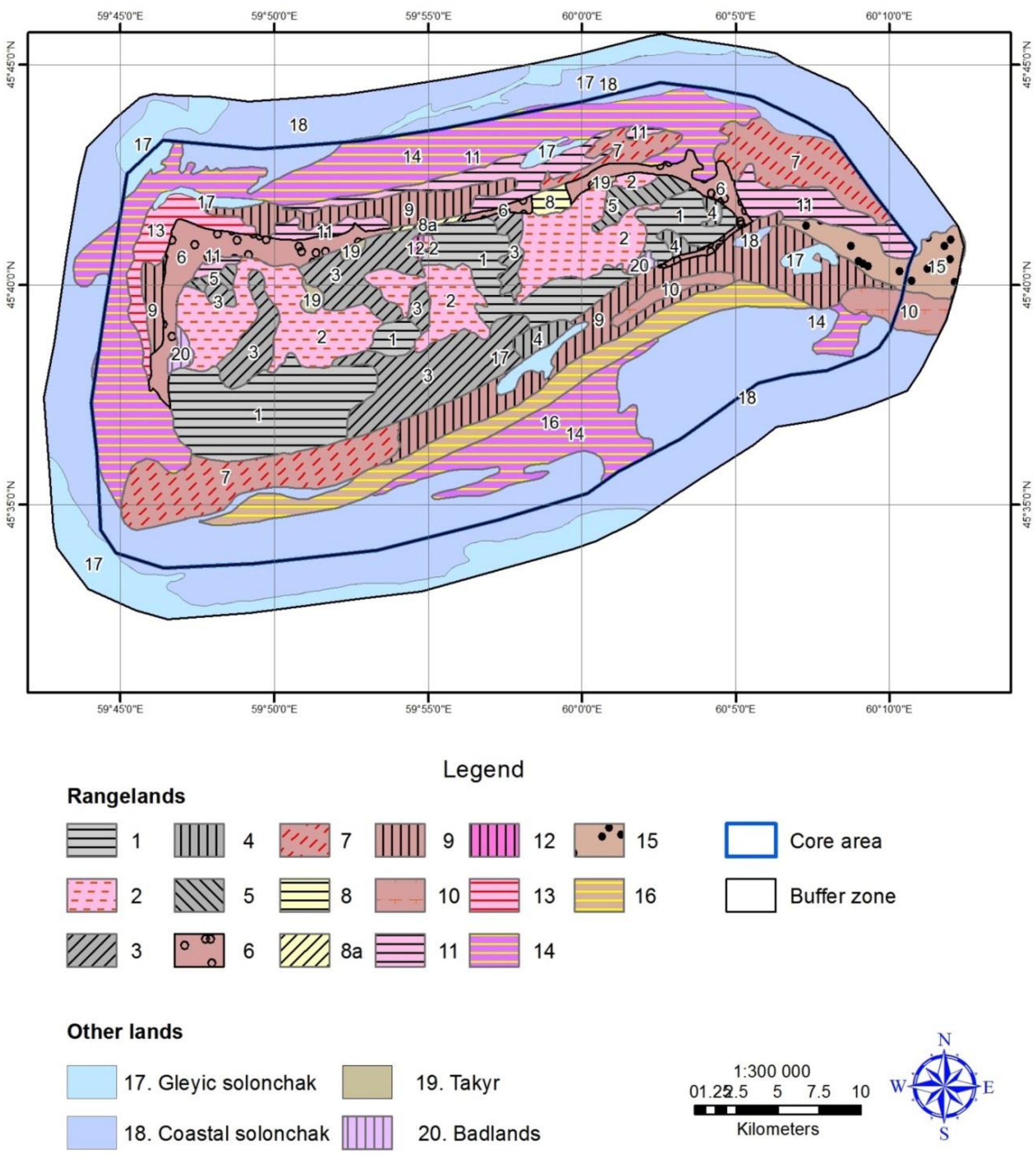

Figure 11. *Rangeland map of the Barsa Kelmes cluster area*

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Seasonal yield maps (*Fig. 10*) were used to highlight the contours. The structure of the legend to the map is based on the principles of the Map of forage lands of Kazakhstan (1978), where each mapping unit shows the yield for seasons (spring, summer, autumn, winter). Seasonal yield was calculated on a basis of the coefficients (Ospanov, 1995) (*Table 5*). For plants that are not on the list, the coefficients were calculated using other sources (Dimeyeva, 1990, 1994).

Table 5. *Coefficients for the dynamics of growth and preservation of the phytomass for one-year growth, %*

Plant name	Seasons of a year			
	Spring	Summer	Autumn	Winter
Stipa lessingiana	80	100	70	60
Agropyron desertorum	70	100	80	60
Stipagrostis pennata	80	100	90	80
Aeluropus littoralis	80	100	60	50
Phragmites australis	50	100	80	70
Eremopyrum orientale, Bromus tectorum	100	60	30	20
Poa bulbosa	100	50	40	20
Alhagi pseudalhagi	30	100	90	70
Ephedra distachya	50	100	90	60
Calligonum aphyllum	100	80	30	10
Haloxylon ammodendron	40	100	80	50
Artemisia terrae-albae	80	100	90	60
Artemisia quinqueloba	60	100	90	60
Anabasis salsa	50	100	90	60
Halostachys belangeriana (Moq.) Botsch., *Kalidium foliatum*	40	100	80	70
Halocnemum strobilaceum	30	100	90	60
Ceratocarpus arenarius	30	100	80	30
Climacoptera aralensis	50	100	90	70
Salsola nitraria	40	100	80	60

The legend to the rangeland map (*Table 6*) is a system of titles to which the mapped units are subordinated. Each mapping unit of the legend corresponds to the type of rangeland that are combined by relief. The headings of the first and second rank reflect the confluence of vegetation to zonal conditions for the formation of forage lands (desert rangelands) and life forms of dominant plants. The total yield for different year seasons is given for each mapping unit, which is the sum of the aboveground phytomass of the community species. In mapping units with complex vegetation, the total yield is the average of its constituent components.

Table 6. *Legend to the rangeland map of the Barsa Kelmes cluster area*

No	Mapping unit	Rangeland aboveground phytomass (dry weight, centner per ha)			
		Spring	Summer	Autumn	Winter
Desert rangelands					
Sagebrush and Anabasis dwarf semi-shrub rangelands					
1	Ephemeroid – sagebrush, sagebrush – anabasis, sagebrush – bulbous bluegrass (*Artemisia terrae-albae, Anabasis aphylla, Poa bulbosa, Tulipa biflora* Pall., *Rheum tataricum*) on plateau and undulating plain	9.4	11.6	10.4	7.0

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2	Anabasis, annual saltwort, ephemeral – anabasis (*Anabasis salsa, Climacoptera brachiata, Eremopyrum orientale*, *Lepidium perfoliatum*) on plateau and undulating plain	4.1	8.3	7.5	5.0
3	Complex of sagebrush – anabasis, anabasis – sagebrush (*Artemisia terrae-albae*, *Anabasis salsa*, *Anabasis aphylla*) with feather grass (*Stipa lessingiana*) on plateau and undulating plain	6.8	10.0	9.0	6.0
4	Sagebrush, ephemeroid – anabasis, salsola (*Artemisia terrae-albae, Anabasis salsa, Allium decipiens* Fisch. ex Schult. & Schult.f., *Ferula canescens* (Ledeb.) Ledeb., *Salsola orientalis* S. G. Gmel.) in combination with bulbous bluegrass – sagebrush, wheat grass – aeluropus, feather grass (*Artemisia schrenkiana* Ledeb., *A. nitrosa*, *A. scopiformis* Ledeb., *Poa bulbosa*, *Agropyron desertorum, Aeluropus littoralis, Stipa lessingiana)* on eroded slopes of plateau and ravines	7.4	10.3	8.3	5.7
5	Sagebrush with feather grass, bulbous bluegrass and haloxylon (*Artemisia terrae-albae, Stipa lessingiana, Poa bulbosa, Haloxylon ammodendron)* on pre-sand plain	6.0	7.6	6.8	4.6
Haloxylon woodland rangelands					
6	Haloxylon, ephemeral – haloxylon with psammophytic shrubs, microcoenoses of ephedra and aeluropus (*Haloxylon ammodendron, Calligonum* spp., *Atraphaxis spinosa*, *Eremopyrum orientale, Poa bulbosa, Lepidium perfoliatum, Ephedra distachya, Aeluropus littoralis)* on the hummocky sands of the old Aral marine terrace	3.4	8.6	6.9	4.3
7	Haloxylon, annual saltwort – haloxylon with tamarisk and psammophytic shrubs (*Haloxylon ammodendron, Tamarix laxa, Astragalus brachypus, Calligonum aphyllum, Atraphaxis spinosa, Salsola nitraria, Atriplex pratovii)* on a slightly hummocky primary marine plain	1.1	3.0	2.4	1.5
Psammophytic shrub rangelands					
8	Psammophytic wormwood – psammophytic shrub with ephedra and tamarisk (*Ammodendron conollii, Calligonum* spp., *Artemisia arenaria, A. quinqueloba, Ephedra strobilacea* Bunge, *E. distachya, Tamarix laxa)* on the hummocky sands of the old Aral marine terrace	3.6	5.6	4.2	2.4
8a	Psammophytic shrub with ephedra, tamarisk and haloxylon (*Calligonum* spp., *Atraphaxis spinosa, Ephedra distachya, Tamarix laxa)* on the hummocky sands of the old Aral marine terrace	3.2	6.4	5.2	3.0
9	Psammophytic shrub in combination with tamarisk (*Astragalus brachypus, Calligonum aphyllum, Eremosparton aphyllum*, *Tamarix laxa*) on hummocky sands of a primary marine plain	3,0	4,9	4,0	2,5
10	Rare aggregations of psammophytic shrubs, haloxylon, stipagrostis (*Calligonum aphyllum,*	1.8	4.0	3.1	2.1

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	Atraphaxis spinosa, Haloxylon ammodendron, Stipagrostis pennata) on a primary marine plain				
Saltwort rangelands					
11	Perennial saltwort with halophytic herbs (*Halocnemum strobilaceum, Kalidium foliatum, Salsola paulsenii* Litv., *Frankenia hirsuta* L., *Limonium otolepis* (Schrenk) Kuntze) on a hummocky primary marine plain	1.8	5.1	4.4	4.4
12	Annual saltwort with anabasis and ephemerals (*Halimocnemis karelinii* Moq., *Climacoptera brachiata, Anabasis salsa, Lepidium perfoliatum*) on flat depressions of takyrs	1.7	3.3	3.0	2.3
13	Orach with single tamarisk (*Atriplex pratovii, Tamarix laxa*) on a slightly undulating primary marine plain	1.7	2.9	2.3	1.7
14	Rare aggregations of orach and sea blite (*Atriplex pratovii, Suaeda acuminata*) on a slightly undulating primary marine plain	< 1	< 1	< 1	< 1
Nitrebush, tamarisk shrub rangelands					
15	Nitrebush and tamarisk with psammophytic shrubs, haloxylon, annual saltworts (*Nitraria schoberi, Tamarix laxa, Astragalus brachypus, Haloxylon ammodendron, Salsola nitraria, Atriplex pratovii)* on a hummocky primary marine plain	1.8	4.6	3.8	2.3
16	Rare aggregations of tamarisk and annual saltworts (*Tamarix laxa, T. hispida, Atriplex pratovii, Suaeda acuminata*) on a slightly undulating primary marine plain	< 1	< 1	< 1	< 1

Discussion

Comparative analysis of the food ration of wild ungulates in the Barsa Kelmes Nature Reserve and other populations both in Kazakhstan and beyond its borders showed that the species composition of the reserve’s forage plants is extensive, despite the limited size of the former island (186 sq. km) and the relatively low species composition of plants (264 species).

Of the total diversity, 105 species are food for wild ungulates (40%). Geographical distribution and species diversity determine food preferences. For saiga inhabiting Kazakhstan, 85 species of plants are forage, in the Barsa Kelmes – 35 species.

For Turkmen kulan, 109 species are fodder plants throughout its distribution (Solomatin, 1977). The studies in the Altyn Emel National Park (Shakula and Khabibrakhmanov, 2014) revealed an extensive list of edible species for kulan (110). It is worth noting that the kulan population was formed from 20 heads removed from the Barsa Kelmes at the end of the 80s last century. Forage ration of the Barsa Kelmes kulan includes 71 species.

According to literary sources, the gazelle in Kazakhstan eats about 70 species of plants (Sludskiy, 1977), in Xinjiang – 47 species (Xu et al., 2012b), detailed studies of Zhevnerov (1984) in the Barsa Kelmes revealed 78 species.

The forage ration in different habitats of wild ungulates may differ. But similarities can be seen in seasonal preferences. In spring, ungulates prefer young shoots of cereals,

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ephemerals, sedges. In summer, annual and perennial saltworts appear in the diet, such as *Atriplex tatarica, Ceratocarpus arenarius, Bassia prostrata*. In autumn, the share of juicy saltworts and sagebrush species increases. In winter, the forage ration consists of annual shoots of haloxylon, shrubs, and dwarf semi-shrubs.

For the wild ungulates of the Barsa Kelmes, it is worth noting that in winter they can feed on the shoots of *Halocnemum strobilaceum*; saiga and gazelle – of ephedra. The berries of ephedra and nitrebush are eaten by gazelles in summer. *Krascheninnikovia ceratoides* is eaten by gazelles in the Barsa Kelmes and in Xinjiang. Kulans of the Barsa Kelmes usually do not eat tamarsk, but in Altyn Emel National Park they feed young twigs. Young shoots of feather grass willingly eat all reserve ungulates in spring, but do not use them in other seasons. We can compare with populations of kulan and gazelle in Xinjiang, where they eat *Stipa caucasica* in spring and summer, and gazelles – throughout the year. Saigas of the northwestern Caspian region use feather grass to a minimum in their forage diet.

The rangeland productivity in the Barsa Kelmes cluster area in 2019 turned out higher compared to the retrospective data of the last century. This is due to a long absence of grazing.

According to the data of the 70s and 80s, the productivity of *Anabasis salsa* communities at the early summer on the island varied from 2.7 to 12.6 c/ha, and in 2019 this indicator increased to 14.5-21.8 c/ha. Also, in 2019 a high yield of the *Artemisia terrae-albae* community was noted – 17.8-23.0 c/ha, and in retrospective data it was 7.8-14.3 c/ha.

Figure 12 shows comparative data on the yield of *Artemisia terrae-albae* and *Anabasis salsa* communities at ecological sites in the early summer season.

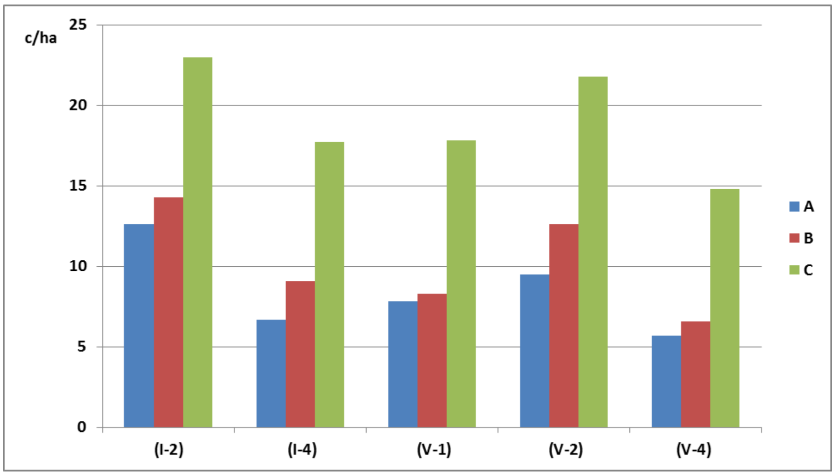

Figure 12. *Comparative characteristics of the aboveground phytomass productivity of zonal communities in the Barsa Kelmes cluster area (early summer season): A – average yield (1976-1979), B – maximum yield (1976-1979), C – yield in 2019; communities: (I-2) Artemisia terrae-albae; (I-4) Anabasis salsa; (V-1) Artemisia terrae-albae; (V-2) Anabasis salsa; (V-4) Artemisia terrae-albae – Stipa lessingiana – Agropyron desertorum*

Phytomass in *Artemisia terrae-albae* communities increased by 38-55% compared to retrospective data, which correlates with the earlier conclusions about an increase in yield by 1.3-2 times in the absence of grazing. In *Anabasis salsa* communities, the yield

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increased by 42-49% compared to the maximum indicators for this season in the 70s. The previously put forward assumption about the decrease of phytomass in *Anabasis salsa* communities in the absence of grazing does not coincide with the indicators obtained in 2019. Most likely this is due to the very long (20 years) period of the rangeland rest.

In 2019, the productivity of haloxylon in *Haloxylon ammodendron* - *Calligonum aphyllum* - *Ephedra distachya* with *Tamarix laxa* com. on the sands in the early summer season was 15.7 c/ha. Indicators of accumulation of haloxylon phytomass in different communities of the sandy desert in the 70s varied from 1.0 to 5.4 c/ha in the same season, the long-time average productivity of haloxylon in early summer over 10 years (70-80s) was 4.7 c/ha (from 0.8 to 7.8 c/ha). The lack of grazing has led to the fact that the sands of the old Aral marine terrace are 90-100% overgrown with desert moss (*Tortula desertorum* Broth.), which usually prevent the regrowth of haloxylon. However, this did not prevent an increase in the productivity of phytomass and it is associated with an increase in the average size of model bushes. On the other hand, *Haloxylon ammodendron* is developing new sandy areas of the dry seabed, where its yield is still low – 2.8 c/ha.

The newly developed rangeland map clearly shows the distribution of rangeland types and their seasonal productivity. The map is an important tool for understanding the scale and structure of rangeland vegetation, predicting habitats for wild ungulates, and modeling the succession status of vegetation under climate change in conditions of zonal ecosystems and the dry seabed. The map also provides data to estimate the extent of carbon sequestration. At last, it provides important information for understanding the available forage resources for wild ungulates, which is the basis for wildlife and rangeland management in particular.

Conclusions

Research has been carried out that summed up the study of the forage resources of wild ungulates in the Barsa Kelmes Nature Reserve. They were carried out 20 years after the ungulates left the island after its association with the mainland. Over a long period of rest, the rangelands have fully recovered and increased their productivity.

On the basis of previous studies, the species composition of the forage ration of wild animals of the Barsa Kelmes Nature Reserve was determined. The general list of plants consists of 105 species, which belong to 26 families and 70 genera. Among them 35 species are eaten by saigas, 78 by gazelles, 71 by kulans. 26 species are eaten by all wild ungulates of the reserve (saiga, gazelle, kulan), i.e. 25% of forage plants. In terms of consumption in the first place are the Poaceae species, in the second – species of the Amaranthaceae (Chenopodiaceae) family, in the third place in the saiga and gazelle forage ration – Asteraceae, and in the kulan ration – Brassicaceae; Fabaceae and Polygonaceae are in fourth and fifth places.

Seasonal feed preferences of wild ungulates generally coincide throughout the habitat. In spring they eat ephemerals, especially cereals, green shoots of feather grass and sedges. In summer *Krascheninnikovia ceratoides* and fruits of *Nitraria schoberi* and *Ephedra distachya* appear in the diet. In autumn saltworts and sagebrush are most often eaten, in winter – annual shoots of *Haloxylon* spp., perennial saltworts and sagebrush.

A comparative analysis of rangelands productivity in recent times and researches in the 70-80s last century showed increasing phytomass in 2019 by more than 2 times. This is due to the lack of grazing on rangelands. On the dry seafloor *Haloxylon*

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ammodendron forms a phytomass of 2.8 c/ha, *Nitraria schoberi* – 3.7, *Kalidium foliatum* – 4.3, *Atraphaxis spinosa* – 3.0, *Ephedra distachya* – 0.6 c/ha.

Ground and remote sensing data were used to assess the seasonal yield of rangelands.

A rangeland map of the Barsa Kelmes cluster area has been compiled in a medium scale basing at the interpretation of satellite imagery, field data, and retrospective research. The legend to the map contains 16 mapped units (rangeland types) for which the total yield was calculated for year seasons.

Our research has shown changes in the productivity of rangelands as a result of a long absence of grazing in a specially protected area. Rangeland resources have increased. Ecosystems develop under the influence of natural factors, which must consist of all ecosystem components, including ungulates. An experiment was inadvertently set up, where the ecosystem has no influence of large herbivores on rangelands. Future actions should be aimed at restoring water sources for the balanced functioning of the reserve's ecosystems.

On the other hand, estimating grazing capacity is necessary for successful pasture management in order to balance stocking rates of grazing animals with the ability of the rangeland to provide forage on a sustainable basis. Grazing capacity is a function of the kind and amount of vegetation produced on the rangeland, topographic characteristics of the landscape, and availability of water resources (Smith et al., 2012). Determination of grazing capacity is therefore a complex process that needs to explicitly consider all these components. Estimating grazing capacity will be the future task connected with availability of water resources.

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APPENDIX

Table A1. *List of forage species of wild ungulates in the Barsa Kelmes cluster area*

Families/species	Eaten species by ungulates		
	Saiga	Gazelle	Kulan
Amaranthaceae Juss.			
Anabasis aphylla L.	-	+	+
A. salsa (C. A. Mey.) Benth. ex Volkens (Ledeb.) Benth. ex Volkens	+	+	+
Atriplex cana C. A. Mey. Ledeb.	-	-	+
A. ornata Iljin	-	+	-
A. sagittata Borkh.	-	-	+
A. tatarica L.	+	+	+
Bassia prostrata (L.) Beck	+	+	+
Ceratocarpus arenarius L.	+	+	+
Climacoptera aralensis (Iljin) Botsch.	-	-	+
C. brachiata (Pall.) Botsch.	+	+	-
C. crassa (M. Bieb.) Botsch.	+	-	+
Girgensohnia oppositiflora (Pall.) Fenzl	-	+	+
Halimocnemis karelinii Moq.	-	-	+
H. sclerosperma (Pall.) C. A. Mey.	-	-	+
Halocnemum strobilaceum (Pall.) M. Bieb.	+	+	+
Haloxylon ammodendron (C.A. Mey.) Bunge ex Fenzl	+	+	+
H. persicum Bunge	+	+	+
Krascheninnikovia ceratoides (L.) Gueldenst.	-	+	-
Salsola arbuscula Pall.	-	+	-
S. nitraria Pall.	-	-	+
S. orientalis S. G. Gmel.	-	+	-
Apiaceae Lindl.			
Ferula lehmannii Boiss.	+	+	-
Asparagaceae Juss.			
Asparagus breslerianus Schult. & Schult. f.	-	+	-
A. persicus Baker			+
Asteraceae Giseke			
Amberboa turanica Iljin	-	-	+
Artemisia arenaria DC.	-	+	+
A. pauciflora Weber ex Stechm.	+	+	+
A. quinqueloba Trautv.	-	+	-
A. terrae-albae Krasch.	+	+	+
A. tomentella Trautv.	-	+	-
Rhaponticum repens (L.) Hidalgo (=*Acroptilon repens* (L.) DC.)	+	-	+
Takhtajaniantha pusilla (Pall.) Nazarova	-	+	+
Taraxacum bicorne Dahlst.	+	+	+
Tragopogon ruber S. G. Gmel.	-	+	-
Boraginaceae Juss.			
Asperugo procumbens L.	-	-	+
Brassicaceae Burnett			
Alyssum linifolium Stephan ex Willd. (=*Meniocus linifolius* (Steph.) DC.)	-	+	+
Chorispora tenella (Pall.) DC.	-	+	+
Descurainia sophia (L.) Webb ex Prantl	-	+	+
Euclidium syriacum (L.) R. Br.	-	-	+
Goldbachia laevigata (M. Bieb.) DC.	-	-	+
Lepidium appelianum Al-Shehbaz	-	-	+
L. perfoliatum L.	-	+	+
Leptaleum filifolium (Willd.) DC.	-	-	+

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Litwinowia tenuissima (Pall.) Woronow ex Pavl.	-	-	+
Capparaceae Juss.			
Capparis spinosa L.	+	+	-
Convolvulaceae Juss.			
Convolvulus erinaceus Ledeb.	-	-	+
Cyperaceae Juss.			
Bolboschoenus maritimus (L.) Palla	-	+	+
Carex stenophylla subsp. *stenophylloides* (V.I. Krecz.) T.V. Egorova (=*C. dimorphotheca* Stshegl.)	-	+	-
C. pachystylis J. Gay	-	-	+
Ephedraceae Dumort.			
Ephedra distachya L.	+	+	-
E. intermedia Schrenk & C. A. Mey	-	+	-
E. strobilacea Bunge	-	+	-
Fabaceae Juss.			
Alhagi pseudalhagi (M. Bieb.) Desv. ex B. Keller & Shap.	+	+	+
Astragalus ammodendron Bunge	+	+	+
A. brachypus Schrenk	+	+	+
A. lasiophyllus Ledeb.	-	-	+
Caragana grandiflora (M. Bieb.) DC.	-	+	+
Eremosparton aphyllum (Pall.) Fisch. & C.A. Mey.	-	+	-
Frankeniaceae Desv.			
Frankenia hirsuta L.	+	+	+
F. pulverulenta L.			+
Geraniaceae Juss.			
Geranium linearilobum DC.	-	-	+
Juncaceae Juss.			
Juncus jaxarticus V.I. Krecz. & Gontsch.	+	-	+
Liliaceae Juss.			
Gagea reticulata (Pall.) Schult. & Schult. f.	+	+	-
Tulipa biflora Pall. (=*Tulipa buhseana* Boiss.)	-	+	+
Nitrariaceae Lindl.			
Nitraria schoberi L.	-	+	-
Orobanchaceae Vent.			
Orobanche cernua Loefl.	-	+	-
Plumbaginaceae Juss.			
Limonium otolepis (Schrenk) Kuntze	-	+	+
L. suffruticosum (L.) Kuntze	+	+	+
Poaceae Barnhart			
Aeluropus littoralis (Gouan) Parl.	+	+	+
A. lagopoides (L.) Thwaites (=*A. repens* (Desf.) Parl.)	+	-	+
Agropyron desertorum (Fisch. ex Link) Schult.	+	+	+
A. fragile (Roth) P. Candargy	+	+	+
Bromus lanceolatus Roth	-	+	-
B. oxyodon Schrenk	-	+	-
B. tectorum L.	+	+	+
Calamagrostis epigejos (L.) Roth	-	+	+
Crypsis schoenoides (L.) Lam.	-	+	+
C. alopecuroides (Piller & Mitterp.) Schrad.	-	-	+
Eremopyrum orientale (L.) Jaub. & Spach	+	+	+
E. triticeum (Gaertn.) Nevski	-	+	-
Leymus racemosus (Lam.) Tzvel.	-	+	+
Phragmites australis (Cav.) Trin. ex Steud.	-	+	+
Poa bulbosa L.	+	+	+
Puccinellia gigantea (Grossh.) Grossh.	-	+	-
Secale sylvestre Host	-	+	-

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Stipa arabica Trin. & Rupr. (=*S. caspia* C. Koch)	+	+	+
S. caucasica Schmalh.	+	+	+
S. lessingiana Trin. & Rupr.	+	+	+
Stipagrostis pennata (Trin.) de Winter	-	+	+
Polygonaceae Juss.			
Atraphaxis spinosa L.	+	+	+
Calligonum acanthopterum I.G. Borshch.	-	+	-
C. aphyllum (Pall.) Guerke	-	+	-
C. platyacanthum I.G. Borshch.	-	+	-
Rheum tataricum L.f.	+	+	+
Ranunculaceae Juss.			
Ceratocephala testiculata (Grantz.) Besser	-	+	-
Clematis orientalis L.	-	+	-
Thalictrum isopyroides C. A. Mey.	-	-	+
Rosaceae Juss.			
Rosa persica Michx. ex Juss. (=*Hulthemia persica* (Michx. ex Juss.) Bornm.)	-	+	+
Rubiaceae Juss.			
Galium aparine L.	-	+	-
Solanaceae Adans.			
Lycium ruthenicum Murr.	-	-	+
Tamaricaceae Link			
Tamarix elongata Ledeb.	-	+	-
T. hispida Willd.	-	+	-
T. laxa Willd.	-	+	-
T. ramosissima Ledeb.	-	-	+
Zosteraceae Dumort			
Zostera noltii Hornem.	-	+	-

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