The current state of steppe ecosystems in the arid zone of Mongolia (a case study of the model site of Mandalgovi)

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Abstract. Under the conditions of climate change and intensive anthropogenic impact, the cenotic diversity of steppe ecosystems is changing. This paper presents results of a study of steppe communities in the arid climatic zone of Mongolia, in particular, a key site named “Mandalgovi”. A classification of the vegetation in this territory is carried out using a cluster analysis of the coenoflora. We have identified 2 groups of formations of desert steppes including 5 formations and 12 associations by using a dominant-determinant approach. A relationship of the plant communities with the relief, general moistening, soil fertility, and salinity has been revealed using methods of ecological ordination. A spatial-temporal distribution of NDVI obtained with Landsat data and VEGA-PRO satellite service is analyzed. An increase in the areas with low values of the NDVI index (from 0.0 to 0.1) characteristic of desert steppes is revealed. This is due to a decrease in the phytocenotic diversity, substitution of indigenous species, and introduction of invasive species, thus leading to a drastic transformation of the plant communities.

1. Introduction
In the context of the current global climate change, spatial and temporal shifts occurred in the structures of natural and economic systems. Steppes act as an indicator when studying the spatial-temporal dynamics of landscapes and their response to the modern climate, because they are sensitive to the impact of anthropogenic factors and global climate changes. Mongolia has an exceptionally unique complex of natural and climatic conditions that attracts scientists from very different spheres.

The aridity of the Central Asian climate is caused by a sharp disparity between the large amount of incoming heat and the small amount of precipitation. The increase in the aridity of climate is manifested in a gradual decrease in the projective cover of the plant communities. From north to south, the overall productivity of vegetation decreases, and changes in the structure of communities can be observed [1]. In the context of the global climate change and excessive fragmentation of the natural vegetation cover of the steppe zone, along with a huge variety of modifications of the native and derived phytocenoses, seasonal, fluctuation, and succession changes in the vegetation, the problems of phytocenosis classification and inventory are tasks of great importance [2].

The purpose of this paper is to study the cenotic structure and state of the vegetation cover of the steppe communities of Mongolia using, as an example, the model site of “Mandalgovi”. From this perspective, the following tasks were set: to identify the phytocenotic diversity of the steppe ecosystems, to consider the connection of the plant communities with the environmental conditions, and to analyze the time course of the normalized difference vegetative index (NDVI).

2 Materials and methods

2.1 Characteristics of the study area
To study the diversity of the vegetation cover and the dynamics of the processes of degradation and desertification of lands with arid climatic conditions, we performed expeditionary surveys on a meridional Baikal-Gobi transect between 52 - 42° N and 104 - 108° E in the territories of the Republic of Buryatia of the Russian Federation and Mongolia.
As a model site in the arid climatic zone, a key site was selected in the central part of the Dundgov aimak, 5 km to the south of Mandalgobi (Figure 1). The relief of this territory is characterized by the spread of denudation plains and plateaus with insignificant participation of island low- and medium-scale massifs and wide (often valley-like) lowlands and basins with small lakes and salt marshes [3].

![Figure 1. Mandalgovi model site.](image_url)

2.2 Geobotanical data
The study of the vegetation of the steppe communities was carried out by route geobotanical methods. During the field work 60 complete geobotanical descriptions were completed, a 16-km geobotanical profile was laid, monitoring geobotanical sites (10x10 m) were laid, and the biological productivity of characteristic phytocoenoses was determined. The Latin names of the species are given according to the outline of the flora of Outer Mongolia [4]. For preliminary sorting and processing of the material using ecological scales, the IBIS program was used [5]. Summary tables of the species composition of the phytocoenoses, geographic and ecological biomorphological spectra are obtained. The species are ranked according to the scales of moistening and “nutrient-salinity” of the soil. Detrended correspondence analysis (DCA) has been carried out, and the ecological status has been given to the communities.

2.3 Satellite data
At the Space Research Institute of the Russian Academy of Sciences (IKI RAS), a professional information service for monitoring of renewable biological resources based on satellite data analysis VEGA-PRO has been created and is constantly being improved. A basis of these automated technologies is the analysis of the NDVI time course. An assessment of the temporal dynamics of vegetation according to archival data of the geoportal of IKI RAS for 2001-2018 was carried out [6].

The GPS-tracks of the boundaries of sections obtained during the field work and subsequently converted into vector shapefiles were used as a mask for detecting the site boundaries.
3. Results and discussion

According to the botanical-geographic zoning, the study area belongs to the Northgobi steppe-desert region of the Central Asian (Daurian-Mongolian) subregion of the steppe region of Eurasia, and is characterized by the domination in the desert steppes of Stipa gobica and the participation of Cleistogenes songorica. A rather significant role is played by Allium polyrrhizum [7].

The array of geobotanical descriptions was differentiated using a dominant determinant principle [8] where the differential groups of species are used as determinants. Associations as the main lower taxonomic units are distinguished by differential species and include phytocenoses similar in their floral composition, structure, and conditions of existence.

The taxonomic units of the rank of the group of formations are determined by the biomorphs of prevailing species according to the classification scheme of A.A. Yunatov [9]. For the study area, 2 groups of formations of desert steppes are distinguished, including 5 formations and 12 associations.

The first group of formations of sod grasses desert steppes are characterized by the dominance of caespitose redivive and includes feather Stipa, Cleystogenes, Allium and Carex formations. Stipa steppes prefer gently undulating medium loamy weakly scrubbed plains. In the formation of the communities of feather grass, the main participation belongs to the small feather grass Stipa Klemenzii and Stipa glareosa with an active participation of Allium polirrhizum. The species composition is extremely poor. There are 2 associations. The association of Stipa Klemenzii steppes with the participation of Peganum nigelastrum is characterized by a simplified species composition and has a lower percentage of dominants. There was loss of Stipa glareosa from the grass stand, whose displacement is probably connected with the introduction into the community of the digression-active species of Peganum nigelastrum, which gravitates toward the disturbed grazing places. While S. klemenzii proved to be more stable.

In the communities of the Cleistogenes formation, along with feather grasses, the turf grass - Cleistogenes songorica - takes on an edificatory role. These communities are located along wavy-rugged plains, partly flat slopes. One association was singled out. According to the characteristics of desert steppes given by A.A. Yunatov, small sedges - Carex stenophylla and C. duriuscula - can be found in small numbers and only as a companion species in these communities. However, in the current vegetation cover, the participation of Carex duriuscula is more significant (5-7%). The noted high participation of the alkaloid species Peganum nigelastrum indicates an escalating community digression.

The communities of the Allium steppe are confined mainly to the plains and relatively elevated locations, preferring light loam and loose sandy soils. Allium polirrhizum is an edificator, along with Stipa glareosa [10]. According to the projective cover, the positions of the onion are strengthened and in percentage terms it becomes larger in comparison with the feather grass. According to A.A. Yunatov the Allium polirrhizum was not always found in the desert steppes, and if it was found it was usually in the form of an infusion. However, in modern vegetation this onion is noted in all communities of the isolated formation and in fairly large abundance.

Communities of Carex grow on soils of light mechanical composition with a small content of humus. The main coen-making participants of the communities of this formation are also Allium polirrhizum and Stipa glareosa. In addition, the digression form Carex duriuscula acts as an active edificator. In the grass stand, Lagochilus ilicifolius, Heteropappus altaicus, Dontostemon integrifolius, Convulvulis ammani (digression species) and a rather aggressive element of Setaria viridis are noted.

The group of formations of the dwarf semishrub sod grasses desert-like steppes includes the Salsola formation, where along with the edificatory role of turf grasses, typical semishrubs - Reaumuria songorica and Salsola passerina - are of great importance. Their participation in the projective coverage is maintained at approximately the same level. The formation includes 5 associations. In large transit sairas (temporary water course for the storm water typical for Mongolia) within the present deserts Reaumuria is dominant, but in these phytocenoses it is located in more severe thermal
conditions. It has a deep root system and is sufficiently resistant to the unfavorable conditions and overgrazing.

An interpretation of the relationship of the plant communities with the environmental conditions was carried out using the method of direct ordination multivariate gradient analysis (Fig. 2) implemented in the PAST package with pretreatment of the cenoses descriptions in IBIS. Also, the interpretation was carried out with the help of indirect ordination by the DCA (detrended correspondence analysis) method - a first-line correspondence analysis or a method of mutual averaging [11]. The results obtained are an important complement to each other.

**Figure 2.** Direct multivariable gradient analysis. Distribution of plant communities (relevés) along moisture and nutrient-salinity gradients: Groups of formations are indicated: A – Stipa formation (feather grass), B – Bistorta formation (bistort), C – Allium formation (onion), D – Carex formation (sedge), and E – Salsola formation (saltwort). The continuous line indicates grouping of the plant associations, e.g. group E comprises Convolvolus-Salsola ass. (E1, E2), Low-bunchgrass -Salsola ass. (E3, E5), Kalidium-Salsola ass. (E4, E10). The dashed line indicates grouping of the transitional plant associations, e.g., Achnatherum-Salsola ass. (E6, E7, E8).

The established syntaxons are differentiated in the space of two ordination axes, as can be seen in Figure 2 representing the main environmental factors that limit the development of steppe vegetation. The vertical ordinate axis reflects the role of the complex gradient in the moistening factor. The horizontal axis is the distribution of the communities in relation to the factor of “nutrient-salinity” of soils. On the ordination scheme, the communities are differentiated into two groups corresponding to the rank of the formation groups. The communities of the turf-grass desert steppes (I) with dominance of redivives occupy more moistened (30-50) and less saline (12.5-16.5) positions, while the group of
formations of the semi-shrub-turf desert steppes (II) is located within the boundaries between 20-30 divisions the scale of moistening and with the highest level of salinity (16.5-18). The phytocoenosis substrate was ordered into the following ecological series in terms of the growth of the humidity gradient at the level of formations: Salsola, Allium, Carex, Cleistogenes communities. However, their ecological spaces overlap, which is probably determined by the presence of common types of adventive flora. One formation smoothly flows into another, the boundaries of the phytocenoses are blurred, and there are no sharp discontinuities within the groups of formations.

The habitats with the driest conditions are occupied by Salsola communities (E1-E10), which tend to grow on the salty soils (16.5-17.9). Meanwhile, Achnatherum-Salsola communities are located beyond the group and are shifted to the 37th level of the moisture gradient scale. We associate this fact with the ecological requirements of Achnatherum splendens, which tend to grow on less salty and relatively moist soils. Also, due to the moist and salty substrate, the community with dominance of Cleistogenes songorica (E8) has an isolated position. Allium communities (C1, C5, C6, C12) are located between the 36th-40th level of the moisture gradient scale and the 14.5-15.5 level of the nutrient gradient scale.

The part of coenosis (C7, C8) shifts down to the 30th level of the moisture gradient due to the presence of Reaumuria songarica in the herb layer. They form the ecotone group (2) with Achnatherum-Salsola communities (E6, E7, E9). The Carex communities (D5, D6) are located within the area with the moistest habitat conditions and lower salinity level of the soils (13.5-14). The largest part of the Carex formation (D2, D3, D4, D7, D8) and partially Allium communities (C2, C3, C9) form the ecotone group (1), since they both share the same herb species, such as Dondostemon integrifolius, Convolvulus ammanii, and Petentilla astragalifolia. The Bistorta communities (B2, B4, B5, B6) occupy more moist positions in contrast to the communities of other formations within the 45th-50th level of the moisture gradient and 13.4-14 of the salinity gradient. The Bistorta communities with the Reaumuria species join the ecotone group (2).

It is important to mention that ecological optimums were not identified for few coenoses of the Stipa formation due to the absence of data in the program. Meanwhile, the communities which were subject to direct multivariable analysis are distributed discretely along the moisture and salinity axes. However, the results of indirect ordination revealed that few conenoses of the Stima formation form one isolated group, which prove their classification as a segregated vegetation association. The results of ordination showed an inverse correlation between the moisture and salinity factors: the higher the moisture level, the lower the level of nutrient and salinity of the soils.

The selected model range was mapped to study the structure of the vegetation cover based on the interpretation and field survey data. The map drawn reflects the current state of the vegetation cover and its horizontal structure [12]. It provides the necessary material for monitoring of changes in the selected key area. The "hill model" method [13] reflects the ecological patterns of the distribution of the communities of the investigated territory depending on the relief and their differentiation in space depending on the leading environmental factors - general moistening, nutrient and salinity of the soils (Figure 3).
In the territory of Dundgov aimag (Mid-Gobi) moving from north to south there is a gradual landscape substitute: the desertified steppes of semi-deserts are changed into deserts with saxaul (Haloxylon sp.). Studies showed that in conditions of insufficient moisture (the annual sum of atmospheric precipitation in the territory of Ulziit somon of the southern part of Dundgov aimag is less than 100 mm, the maximal value is 150 mm in the north and complete absence of fresh surface water), the Gobi landscapes are easily affected by degradation processes, especially by physical weathering, deflation, and degradation of vegetation. Even though the general pasture load on the territory of Dundgov aimag is low, because of a rather low density of the animal base, the soil surface around the bases is trodden within a 0.5-0.7 km radius, and there is hardly any vegetation cover (the projective cover: < 10 %).

Southern dry steppe landscapes dominate to the north of the Mandalgovi aimag center. They are located in 70-80 % of the territory. Desertified steppes take up 10-20 %, while saline and alkali saline soils comprise less than 8 %. To the south of Mandalgovi, within the limits of the Mid-Gobi model site, desertified steppe landscapes prevail (65-75 %). The southern steppes take up 20-30 %, and the saline ones comprise less than 9 % of the territory.

The average NDVI value for 2001-2018 for the model Mid-Gobi site is 0.12, which proves poor vegetation (Figure 4). In 2012 and 2013 the NDVI values were much higher than the average values and reached 0.35 (in 2012). The summer of 2012 in the Gobi was abnormally humid, according to local old-timers this was not the case for the last 20-25 years.

The analysis of the NDVI time course shows a decrease in its values in the August of 2011 (from 0.17 to 0.135) and in June (from 0.15 to 0.125). The tendency of the Gobi vegetation for xerophytization shows the NDVI index analysis of the Mid-Gobi territory site from Landsat TM images made in September of 1990 and 2011. Thus, if in September of 1990 75 % of the site area had an NDVI value of 0.0-0.1, in September of 2011 92 % of the areas had values of 0.0-0.1.
The performed natural identification of areas with different NDVI values showed that prevailing values of 0.0-0.1 (92 % of the area) can be observed in stony desert steppes with predominant *Allium polyrrhizum Turcz. ex Regel*, which was popular in the southern Gobi areas in the 1990s. Areas with NDVI values of 0.1-0.2 currently comprising only 8 % of the Mid-Gobi site area are observed for ling and needle grass (*Achnatherum splendens – Carex duriuscula*) of saline, stone-free valleys.

An analysis of meteorological data proved that in the 2000s there was more severe drought during the summer periods than in the previous century, which, in our opinion, is the main factor for the digression tendency in the Gobi vegetation.

4. Conclusions
As a result of the above studies, the present state of the steppe ecosystems of the arid zone of Mongolia (a case study of the model site of Mandalgovi) was estimated, phytocenotic diversity was determined, and ecological relationships of the spatial structure of vegetation were examined with field research and remote sensing data. It has been revealed that the southern steppe landscapes are represented by turf grasses desert steppes characterized by dominant turf grassy perennials with *Stipa, Bistorta, Allium*, and *Carex* formations. The desert-steppe landscapes are represented by semi-shrub-turf grassy desert steppes where, along with edifying turf grasses, typical semi-shrubs, *Reaumuria songorica* and *Salsola passerina* are of great importance. Ecological regularities in the distribution of the communities of the investigated territory have been determined depending on the relief and differentiated by the leading ecological factors - general moistening, soil nutrient and salinity. It was noted that the nature of the steppes varies regularly as they move to the south according to a latitudinal zoning. In the northern part of the model site, southern-steppe communities predominate, occupying 70-80 % of its area and in the southern part, desert-steppe ones (65-75 %). An analysis of the spatial-temporal distribution of the NDVI showed an increase in the areas with low index values (0.0-0.1). This is due to a decrease in the species composition, the loss of steppe herbage replaced by more xerophytic species.

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