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DYNAMICS OF ECOSYSTEMS AND THEIR COMPONENTS

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DYNAMICS OF TERRESTRIAL NATURAL ECOSYSTEMS IN MONGOLIA FOR THE PERIOD OF 1989-2017

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In 1989-1990 the Joint Russian (Soviet)-Mongolian Complex Biological Expedition of the Russian Academy of Sciences and Mongolian Academy of Sciences carried out a mapping and assessment of the natural ecosystems' condition in the entire territory of Mongolia. These complex studies resulted in a synthetic map "Ecosystems of Mongolia" at the scale of 1:1,000,000 that included information about the level of their anthropogenic disturbance (Ecosystems ..., 1995). The map became a starting point for the further monitoring of Mongolian environment. The drastic socio-economic changes that have been affecting the country over the last decades have caused new environmental risks and increased already existing ones, therefore accelerating digression processes and reformation of Mongolian ecosystem continuum. This was the reason for starting a new monitoring research and mapping at the same scale in 2012-2017. The outcome of these long-term studies of Mongolian terrestrial ecosystems was the atlas of Ecosystems of Mongolia (2019), published in English.

The comparison of the data obtained in 1989-1990 and 2012-2017 showed that the total area of natural ecosystems decreased only by 0.5%. However, the analysis of their condition is a definite evidence of increasing degradation processes for the outlined period. Thus, the areas of non-disturbed and slightly disturbed ecosystems reduced by 1/3, the moderately disturbed ones grew by 44%, and the strongly and very strongly disturbed areas increased more than twice. A similar situation can be seen in the ecosystems suitable for pastures.

The main reasons of anthropogenic disturbance are agricultural factors, such as overgrazing, forest fires, cutting, plowing, mining, and growing of residential territories. By 2017, the area of anthropogenic ecosystems grew by 40%, including the plowed up lands as well as industrial and residential ecosystems.

For a detailed study of degradation mechanisms of terrestrial ecosystems under the impact of the main anthropogenic factors, we carried out monitoring and mapping in model somons (divisions), model testing plots and key sites, mainly located in the areas of high environmental tension. As the result, the maps of ecosystems and their anthropogenic disturbance were created at the scale of 1:200,000 and larger; they were also included into the atlas (Ecosystems ..., 2019). These studies helped to make and develop the representative network of model territories for the long-term monitoring covering all nature regions of the country.

Therefore, while comparing the data of 1989-1990 with the newest materials, we were able to calculate the areas currently occupied with various ecosystems, to assess their condition and determine their transformation trends.

Keywords: Mongolia, ecosystems, impact, dynamics, mapping, atlas.
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For the past decades Mongolia is undergoing significant changes in its social and economic areas, such as a substantial increase of population and its wealth, abrupt raise in the numbers of urban residents, growth of market relations, fast development of mining industry, international and domestic tourism, and transport network. At the same time people get more and more concerned about the environmental problems in the country, the most relevant of which are the decrease of native coniferous forests, pasture exhaustion, and water bodies extinction (Altrell, 2019; Tong et al., 2018; Nyamtseren et al., 2018). It all happens along with the general climate warming, annual precipitation decline, and progressing desertification (Dulamsuren et al., 2015).

In the end of the XX century the countryside residents begun to migrate (mainly from the western part of Mongolia) mostly to Ulaanbaatar and other industrial cities and to the large mining areas. The total population of urban community from 1990 to 2017 increased by 75% − from 1,266.5 to 2,146.7 thousand people. For example, the population of Ulaanbaatar, the capital of Mongolia, has grown 2.5 times − from 586.2 to 1,463 thousand; in Erdenet, one of the largest industrial cities, it has grown almost twice − from 51.2 to 99.8 thousand (Ecosystems…, 2019).

Over the recent years the Mongolian economy underwent significant structural changes. The mining industry has turned into a driving force of the local economic and is still getting more important. Thus, the share of agriculture in the country's gross domestic product dropped from 27.4% in 2000 to 10.1% in 2017, while the share of mining industry increased from 11.2 to 24.2% over the same period. It is worth noting that the gold mining activities intensified significantly. The total amount of gold mined in the country increased from 800 kg in 1991 to 15,300 kg in 2015 (NSO, 2018).

Along with rural population severely reducing, the livestock rapidly increases in numbers, therefore exacerbating the already high pasture loads on limited territories. Thus, by 2017 the total amount of livestock increased more than 2.5 times compared to 1990. The number of goats, the most digressively dangerous type of livestock, also increased severely – by 5.3 times. Their growth is caused by high cashmere demand on the market. At the same time the interest for camel breeding subsided, with camels' total number dropping more than 1.2 times (Ecosystems ..., 2019).

By 1989 about 1.15 million hectares of Mongolian territory were plowed. The maximal area occupied with crops was 837.9 thousand ha in 1989 and just 200.5 thousand in 2004 (fig. 1).

For a long time the remaining lands existed only as fallows. The situation began to change after 2007, when the Government Program "Virgin Land-3" (Tselina-3) for Agricultural Producers Support was launched. It aimed to improve the efficiency of agricultural production, such as cereals, potatoes and vegetables. By 2014 the area for crops was already 444.3 thousand ha, while the fallow (and even virgin) lands become constantly involved in crop rotations in modern Mongolia. We should emphasize that such extensive land involvement in plowing activities, especially on the piedmont plains and slopes with soils of light mechanical composition, eventually increases erosion processes and even causes desertification. Thus, currently about 65% of the arable lands of the Selenga River basin, where more than 85% of those lands is concentrated, has suffered from erosion, with 35% of them being moderately and highly eroded (Bazha et al., 2018).

Forests occupy about 8% of Mongolian territory. They are common for mountain systems and concentrated in northern and partially central regions of the country. Due to specificity of the local climate and anthropogenic loads, forest ecosystems are very unstable and recover with great difficulties and can even deteriorate irreversibly. Meanwhile the forestry activities have a less significant impact on forests than some natural factors (climate change, fires, pests) and anthropogenic (mining, overgrazing) ones.

We can assess the risks of demographic, economic, and environmental changes in the country only on the basis of thorough studies of ecosystems' condition, their changes, and dynamic trends. The results of such complex studies are important not only for Mongolia, but also for Russia, especially for Southern Siberia, the natural environment and agricultural features of which are very similar to the ones of Northern Mongolia.

The mapping method is the most descriptive and objective one for studying terrestrial ecosystems and their condition. It uses both the modern materials of remote sensing that cover vast territories simultaneously, and the ground-based complex for field researches that helps to decipher and significantly complement an already existing picture with various actual data. Analysis of mapping data, obtained on the same territories for different years, plays a special role, allowing us to track the dynamics of various processes and quantify these changes.

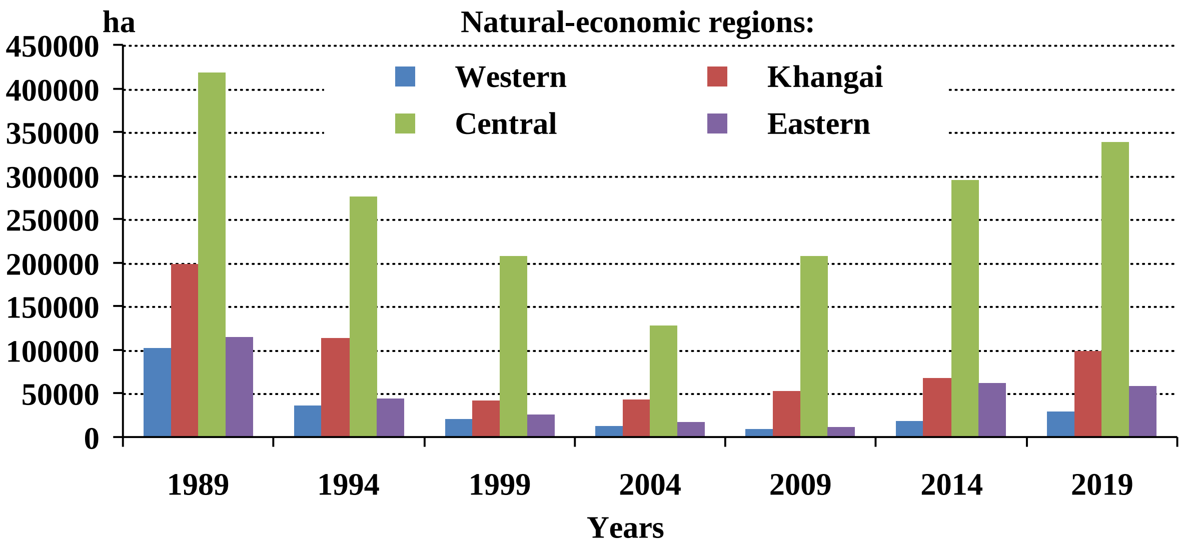


Fig. 1. Dynamics of cultivated areas of Mongolia by natural-economic regions (ha).

The complex study of Mongolian ecosystems by different methods including the thematic mapping has been carried out for 50 years by the Joint Russian-Mongolian Complex Biological Expedition of the Russian Academy of Sciences and Mongolian Academy of Sciences (JRMCBE; previously known as the Joint Soviet-Mongolian Complex Biological Expedition of the Academy of Sciences of USSR and the Academy of Sciences of the Mongolian People’s Republic).

In this article we will talk about analysis of the main changes in terrestrial ecosystems of Mongolia, and identification of what exactly has caused them over the past quarter of the century. Here we use mapping materials compiled by the JRMCBE researchers over the different years and included in the atlas of Mongolian ecosystems (Ecosystems ..., 2019). The atlas data makes it possible to determine trends of long-term changes in the natural ecosystems of Mongolia, to assess the spatial-temporal extent of development and distribution of anthropogenic degradation, and to determine the degree of impact that individual negative factors had on ecosystems.

Objects and Methods of Research

In 1989 during the only field season scientists of the JRMCBE carried out a complex study, prepared maps, and assessed the state of natural ecosystems throughout the entire territory of Mongolia; the deed was unprecedented in its scale. The study was carried out according to the pre-established methods (Methodological Guidelines ..., 1989). It resulted in an “Ecosystems of Mongolia” map at the scale 1:1,000,000 (Ecosystems ..., 1995), which shows the composition and zonal-belt ecosystems structure and main anthropogenic factors of their destabilization, and also the ecosystems’ condition as it was at the time of mapping.

The map legend includes 64 types of zonal-belt and intra-zonal natural terrestrial ecosystems, as well as aquatic and anthropogenic (residential, industrial, and arable) ecosystems. According to the methodological designs (Methodological Guidelines ..., 1989), the degree of anthropogenic disturbance of natural ecosystems was evaluated on the 5-point scale: I – very weak (background), II – weak, III – medium, IV – strong, V – very strong (and usually irreversible).

In 2005 a small atlas of Mongolian ecosystems was compiled and published (Ecosystems ..., 2005). It is based on the data from the map of Mongolian ecosystems (Ecosystems ..., 1995) and along with the various thematic interpretations of that map, it also includes calculated areas of different zonal-belt and ecological groups of ecosystems, indicating their shares throughout the entire territory.

From 2012 to 2017 the CRMCBE employees monitored the current state of ecosystems in every aimag (province) of Mongolia, and did another mapping at the scale of 1:1,000,000. The monitoring of the level of anthropogenic disturbance was carried out within the ecosystems boundaries displayed on the map of Mongolian ecosystems (Ecosystems ..., 1995); only the boundaries of anthropogenic ecosystems were corrected (of the new ones and the significantly transformed old ones). These materials were used to create the “Ecosystems of Mongolia” atlas that was published in 2019. The atlas included numerous thematic maps, created as the part of the JRMCBE Scientific Program and dedicated to the natural complexes of various regions, model testing plots, somons (divisions) and nature protection territories of the country. These model plots were used to try out the modern methods of mapping of ecosystems and their condition, and identifying degradation factors (Bazha et al., 2013). Besides, the atlas included some maps, tables and graphs showing the changes of many social and economic indices from 1990 to 2017.

The atlas (Ecosystems ..., 2019) is compiled on the regional basis, and aside from the general section it includes 4 regional ones that combine maps and statistical data of the 4 natural-economic regions (NER), into which the territory of Mongolia is divided, taking into account their natural features, economic indices and administrative borders of each aimag. The Western NER contains 5 aimags: *Bayan-Ulgii, Khovd, Uvs, Zavkhan,* and *Govi-Altai*. Khangai NER includes *Khuvsgul, Bulgan, Orkhon, Arkhangai, Ovorkhangai,* and *Bayankhongor* aimags. The Central NER includes *Selenge, Darkhan-Uul, Tuv (Central), Dundgovi, Dornogovi, Umnugovi* aimags and an administrative territory of *Ulaanbaatar* city. The Eastern NER includes *Khentii, Dornod,* and *Sukhbaatar* aimags (fig. 2).

Each NER has a meridian direction, spreading from the northern to southern country borders; therefore, all the latitudinal natural zones of Mongolia fall within the territory of each region. Natural diversity gradually decreases from west to east, as well as the landscape contrast of the regions. Out of the 64 natural ecosystems highlighted on the map of Mongolian ecosystems (Ecosystems ..., 1995), 62 are presented in the territory of the Western NER, 61 in Khangai, 58 in the Central, and only 38 in the mostly flat Eastern NER.

The atlas sections with image maps of each NER (Ecosystems ..., 2019) include large-scale maps of ecosystems and their anthropogenic disturbance for the territories of some somons, model testing plots and key sites, located in the regions of high environmental tension.

Results and Discussion

These maps were created to provide a detailed study of degradation processes of terrestrial ecosystems under the influence of the main anthropogenic factors, such as forestry, agriculture, mining industry, and recreation activities, as well as the degree of their impact on the natural ecosystems condition. The model testing plots and somons, which mapping was carried out mainly at the scale of 1:200,000 and characterized by a significant variety of natural complexes, became the basic territories for inventory and determination of the level of anthropogenic disturbance of their ecosystems, and detection of their specific degradation processes. The key sites were selected to study thoroughly factors of anthropogenic impact and hazardous processes of degradation. Their mapping was carried out at the larger scale, mainly at 1:10,000.

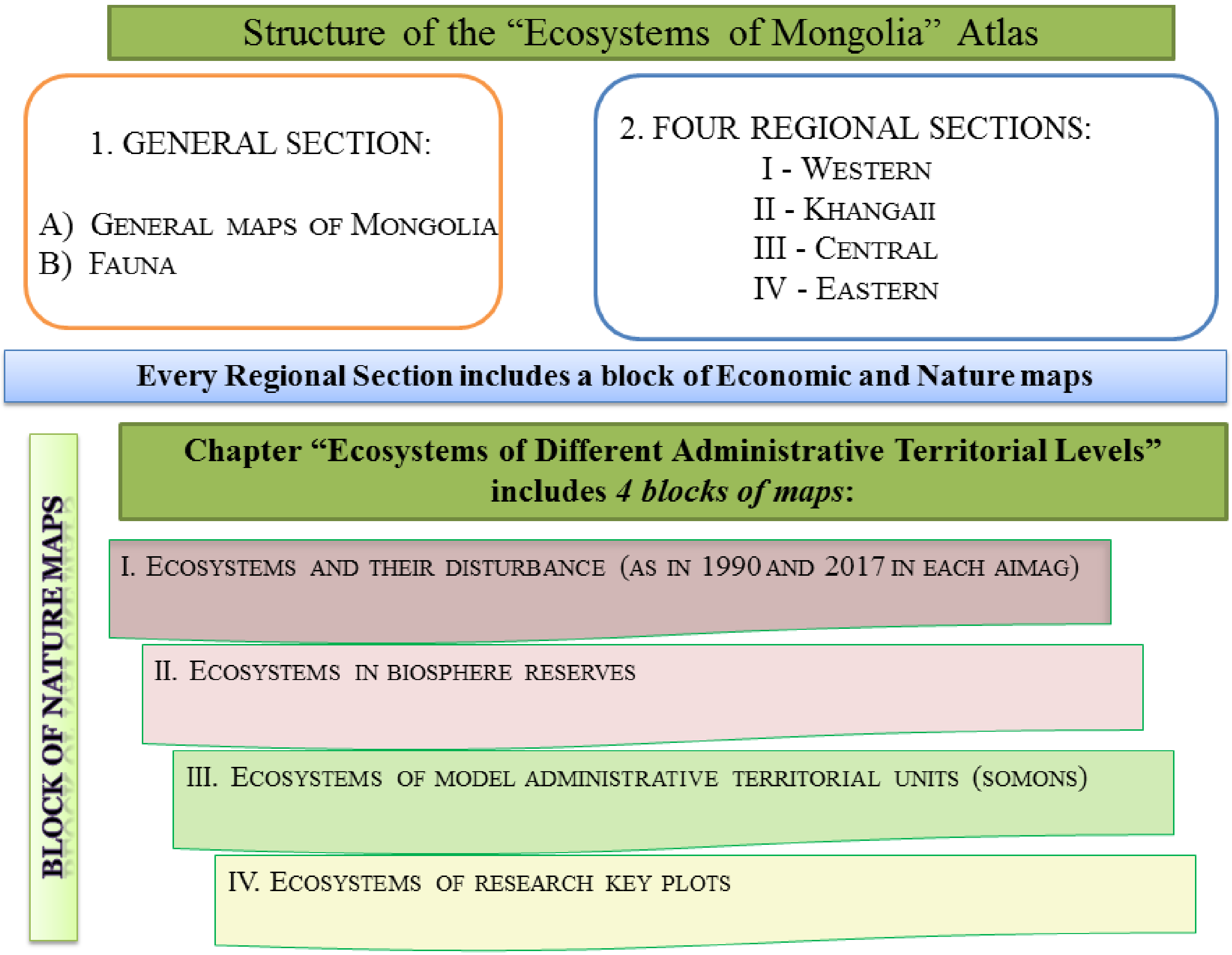


Fig. 2. Structure of the "Ecosystems of Mongolia" atlas (2019).

The atlas was made in a digital format; all included maps were created on the basis of GIS-technology, which established a direct relation between specific map sections and their quantitative and qualitative characteristics, allowing us to make some necessary calculations and analytics, which underlined this study.

Area evaluation of ecosystems, suitable for pastures. On the basis of the processed data of "Ecosystems of Mongolia" (2005) at the mapping scale of 1:1,000,000, we received the area data for those ecosystems which were suitable for the grassland farming, which is a traditional stem of Mongolian economy (table 1). The ecosystems were considered suitable if their vegetation had a feeding value and was available for livestock grazing.

Despite the fact that suitable ecosystems occupy about 86% of the country territory, the large areas of them currently cannot be used as intended due to some reasons. Some of them are as follows:

- territories of extremely arid and true deserts in the south of Mongolian and Gobi-Altai mountain systems; individual desert and semi-desert territories in the Great Lakes Depression, Gobi Valley of Lakes, and some ecosystems of dry steppes and desert steppes in the east are unusable due to the lack of fresh water sources;

- large massifs of drifting and semi-stable sands are unusable due to extremely sparse grass, risk of erosion development, and absence of water sources (photo 1);
- many alpine peaks of Khentii, Khangai, and Mongolian Altai are unusable due to their remote location from watering places and settlements, and their inaccessibility.

Table 1. Area of ecosystems suitable for Mongolian pastures (based on materials of 1989).

Ecosystems	Area, thousands km^2	% of the area of Mongolia
Ecosystems suitable for pastures		
Zonal-belt (*highland*: cryophytic groups, with cushion plants, tundra, with dwarf birch, with Kobresia; *plain and mountain steppes:* highland, meadow, moderately dry, dry, dezertified, desert; *deserts:* northern, southern, extremely arid) and **hydromorphic** (non-forest) − bogged and floodplain meadows, bogs, solonchaks	1345.02	86.0
Ecosystems unsuitable for pastures	219.1	14.0
Natural (*aquatic:* lakes, large rivers; *forest:* mountain, mountain valley, floodplains; *nival:* glaciers, snowfields, stony surfaces, rocky outcrops)	199.7	12.8
Anthropogenic (*plowed areas:* arable lands, fallow lands, plantations; *industrial and residential areas:* developed mineral deposits, construction sites, settlements, infrastructure)	19.4	1.2
Natural ecosystems	1544.72	98.8
Mongolian territory	1564.12	100.0

The usage of some pastures is limited because territories can maintain only one livestock species:

- moss-lichen tundra, subalpine thin forests and forests with dwarf birch in Khuvsgul Region are the pastures for reindeers;
- extremely arid deserts, most of the true deserts and semi-stable sands, stabilized by sparse shrubs and semi-shrubs are for camels;
- highland meadows and rocky tundra, remote from the inhabited valleys, in Mongolian and Gobi Altai, Khangai and Khentii are available only for yaks;
- lithophytic steppe ecosystems of rocky, highly divided ecotopes with steep slopes are suitable only for goats (photo 2).

Climatic factor also significantly limits possibilities of livestock increase. The common features of Mongolian climate are aridity, uneven precipitations, and their abrupt yearly fluctuations. Over the past 20-25 years we registered a growth of dry years (Zhargalsaikhan, 2008; Bazha et al., 2018). Moreover, the average temperatures, both for a year and for a vegetation period, grew highly in many regions compared with the average long-term data (Gunin et al., 2015; Bazha et al., 2018; Bogdanov et al., 2019).

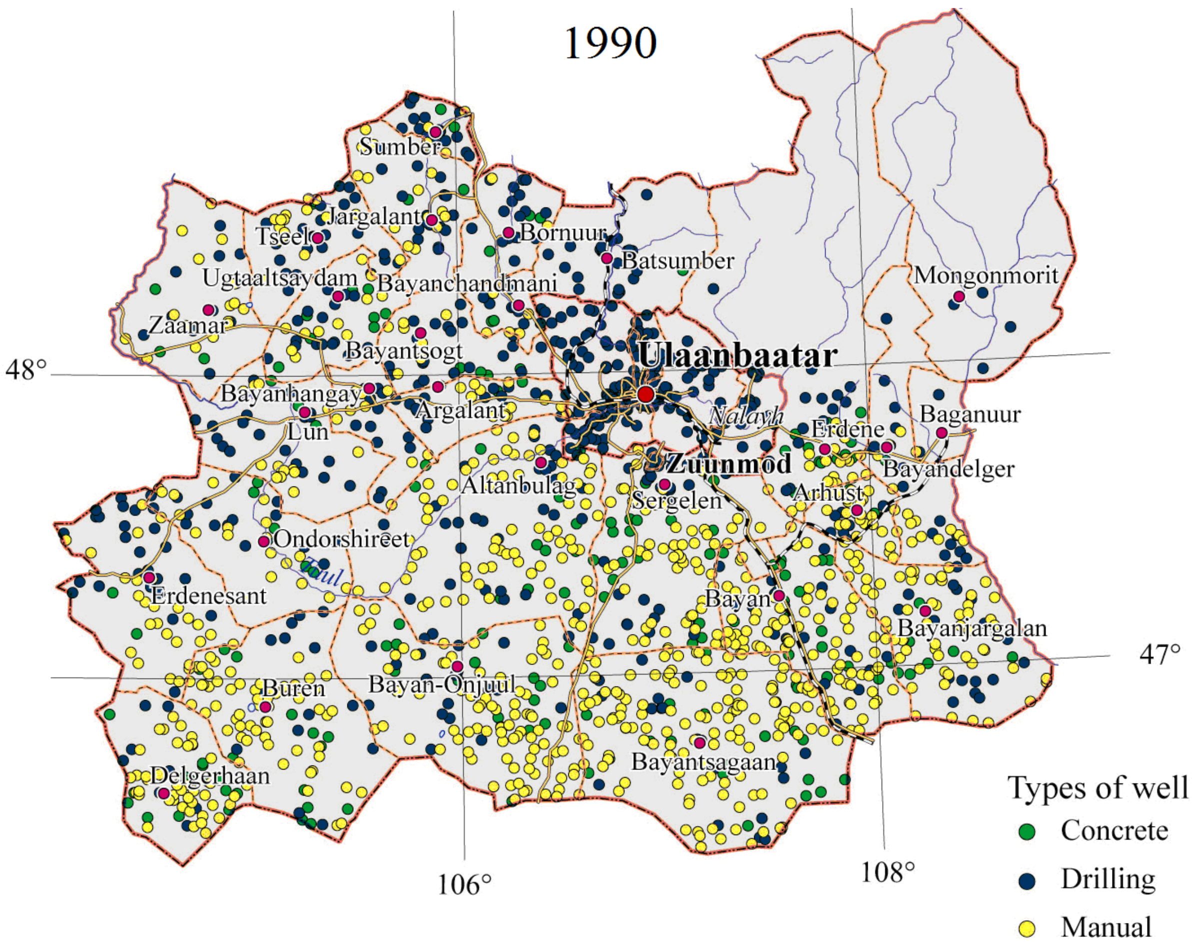
Water provision for the livestock was always an acute issue in Mongolia due to its climate aridity. Even during the age of the Mongol Empire, the great Khan Ogedei, who ruled in 1229-1241, commanded to build irrigation structures: “I ordered to dig wells in the waterless lands, thus bringing water and food to people” (Kozin, 1941). Unfortunately, it is hard to tell yet whether his plans were implemented or not.

Photo 1. Waved sands are unsuitable for grazing (Omnogovi aimag).

Photo 2. Highly stony pastures are suitable for goats (Bayanhongor aimag).

The water supply problem was brought up again only during the years of “people’s power”, in the second half of the XX century with the active help of USSR specialists and countries from the Council for Mutual Economic Assistance. On a scheduled basis Mongolia started building a network of wells and watering sources for livestock. Some relevant hydrogeological surveys were carried out along with the forage and botanical studies and economic calculations. Generally, all the plans were fulfilled, but due to the socialist system crisis in the late 1980s the state lost all its control over the wells condition. As a result, a significant number of them were out of service.

By an example of the most economically developed and populated Tuv aimag we can study negative dynamics of water supply of the pastures for the 25-year-long period (fig. 3). By the time the big socio-economic reforms began, there were more than 1,500 thousand wells spreading more or less evenly over the aimag territory (excluding the highland northeastern part). For a quarter of century their total number decreased by 36%. The severe decline of functioning wells was primarily caused by the fact that most of them used compressors for water supplying, many of which were destroyed.



Aymag	Types of well			
	Concrete	Drilling	Manual	Subtotal
Tov	165	496	854	**1515**

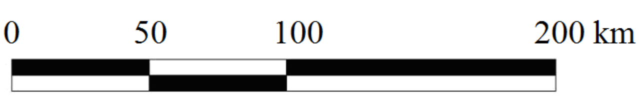
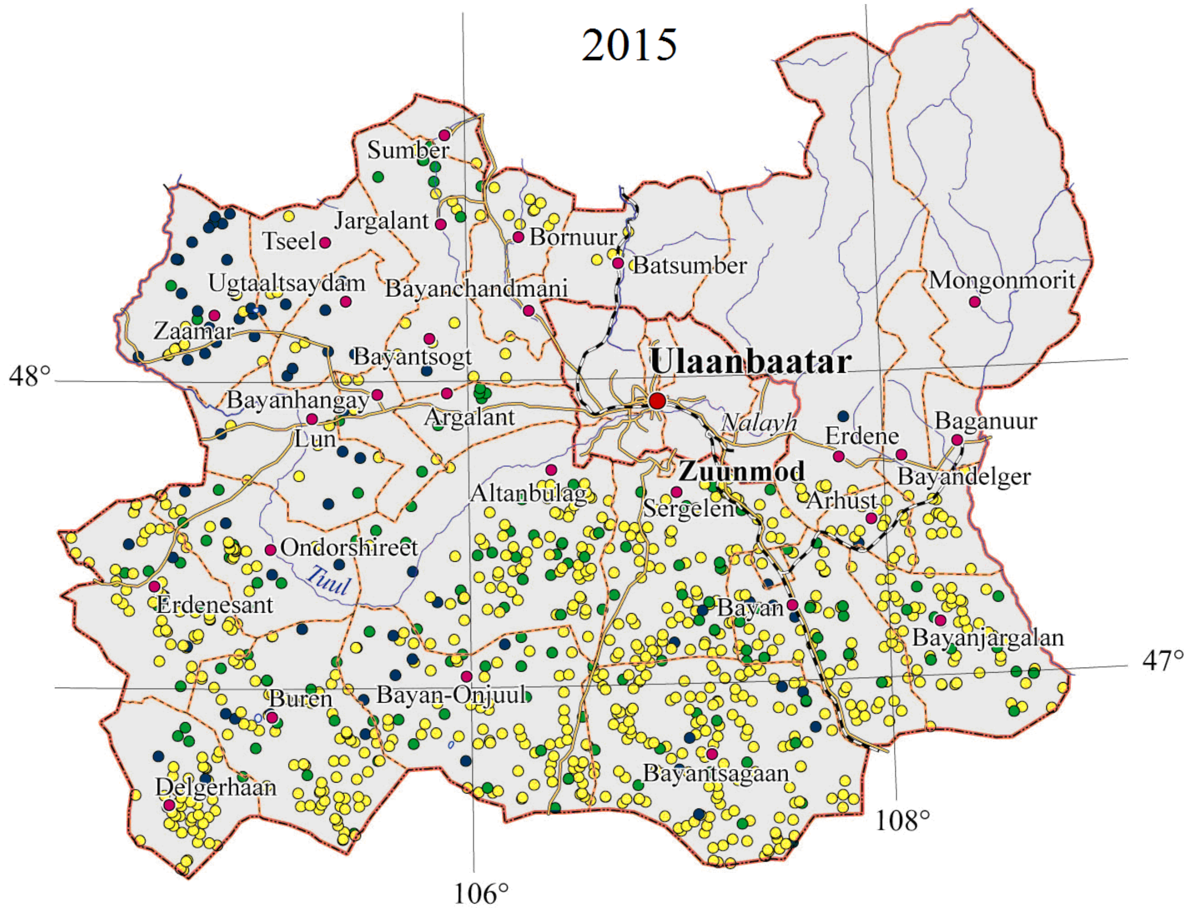


Fig. 3 a. Distribution of water sources in the Central aimag in 1990 (Ecosystems…, 2019).



Aymag	Types of well			
	Concrete	Drilling	Manual	Subtotal
Tov	151	77	742	**970**

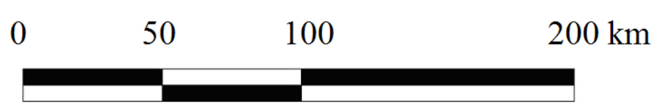


Fig. 3 b. Distribution of water sources in the Central aimag in 2015 (Ecosystems…, 2019).

Other aimags are also not doing that good, therefore causing two kinds of consequences. On the one hand, some of the pastures are out of use due to absence or lack of water. On the other hand, loads on the existing watering points gets more severe, depleting and polluting the groundwater reserves, as well as accelerating degradation of vegetation and soil cover around the wells (photo 3). Since Mongolian economy focuses now on a resource model, the government does not pay enough attention to supporting cattlemen, so usually the private farmers become the ones to maintain these wells.

Many studies show that feeding productivity potential of Mongolian pastures is very limited (Fujita et al., 2013). The livestock numbers exceeded feeding capacity of pastures already by the mid and late 1990s (Gunin et al., 2003, 2009). However, throughout the country they grow quickly, therefore causing more and more pasture loads on Mongolian ecosystems. For the study period their growth was more than 1.9 for all the NERs. The highest livestock increase was registered in the Western and Khangai NERs (table 2). The series of the atlas maps displays it clearly, showing the livestock density by their species for every NER (Ecosystems…, 2019). Figure 4 shows an example of these maps with the goat density for the Central NER in 1990 and 2017.

Photo 3. A degraded pasture with *Peganum nigellastrum* surrounding a well (Dundgovi aimag).

Table 2. Mongolian livestock composition in 1990 and 2017 (thousands of heads).

Livestock	Year	Natural-economic regions				Total in Mongolia
		Western	Khangai	Central	Eastern	
Sheep	1990	5111.78	4526.81	3164.33	2214.24	15017.16
	2017	**6903.22**	**11329.00**	**6678.15**	**5029.34**	**29939.71**
Goats	1990	1977.92	1538.68	1213.07	378.52	5108.19
	2017	**7702.37**	**9613.56**	**6619.97**	**3289.78**	**27225.68**
Horses	1990	562.20	789.54	542.35	352.67	2246.76
	2017	**676.12**	**1439.70**	**902.30**	**878.36**	**3896.48**
Cows and yaks	1990	692.36	1134.86	521.17	455.38	2803.77
	2017	**815.96**	**1934.45**	**769.25**	**779.95**	**4299.61**
Camels	1990	155.45	90.67	252.19	39.15	537.46
	2017	**103.91**	**88.09**	**223.75**	**18.10**	**433.85**
Total	1990	8499.70	8080.56	5693.11	3439.95	25713.32
	2017	**16201.58**	**24404.79**	**15193.41**	**9995.54**	**65795.32**

The numbers of Mongolian livestock still grow to this day, and by the early 2019 it had already reached 66,460.18 thousand heads (NSO, 2018). As a result of the increasing numbers of domestic animals and decreasing numbers of rural population, the herds that were maintained by some cattlemen families (arats) grew bigger. Thus, by 2017 the amount of these families dropped by more than 20%, while the average number of their herds increased. For example, since 2012 the number of cattlemen who own more than 2,000 heads of livestock has become thrice bigger; the number of cattlemen with the herds of 200-500 heads has increased by 30%, and those who own less than 10 animals decreased by 20%. The large herds are less mobile and more dependent to the arats' camps, they destructively affect pasture ecosystems, especially the most productive ones and comfortable for grazing, located near watering places, around settlements and camps (Syrtypova, Chyltemsuren, 2015; Lkhagvadorj et al., 2013).

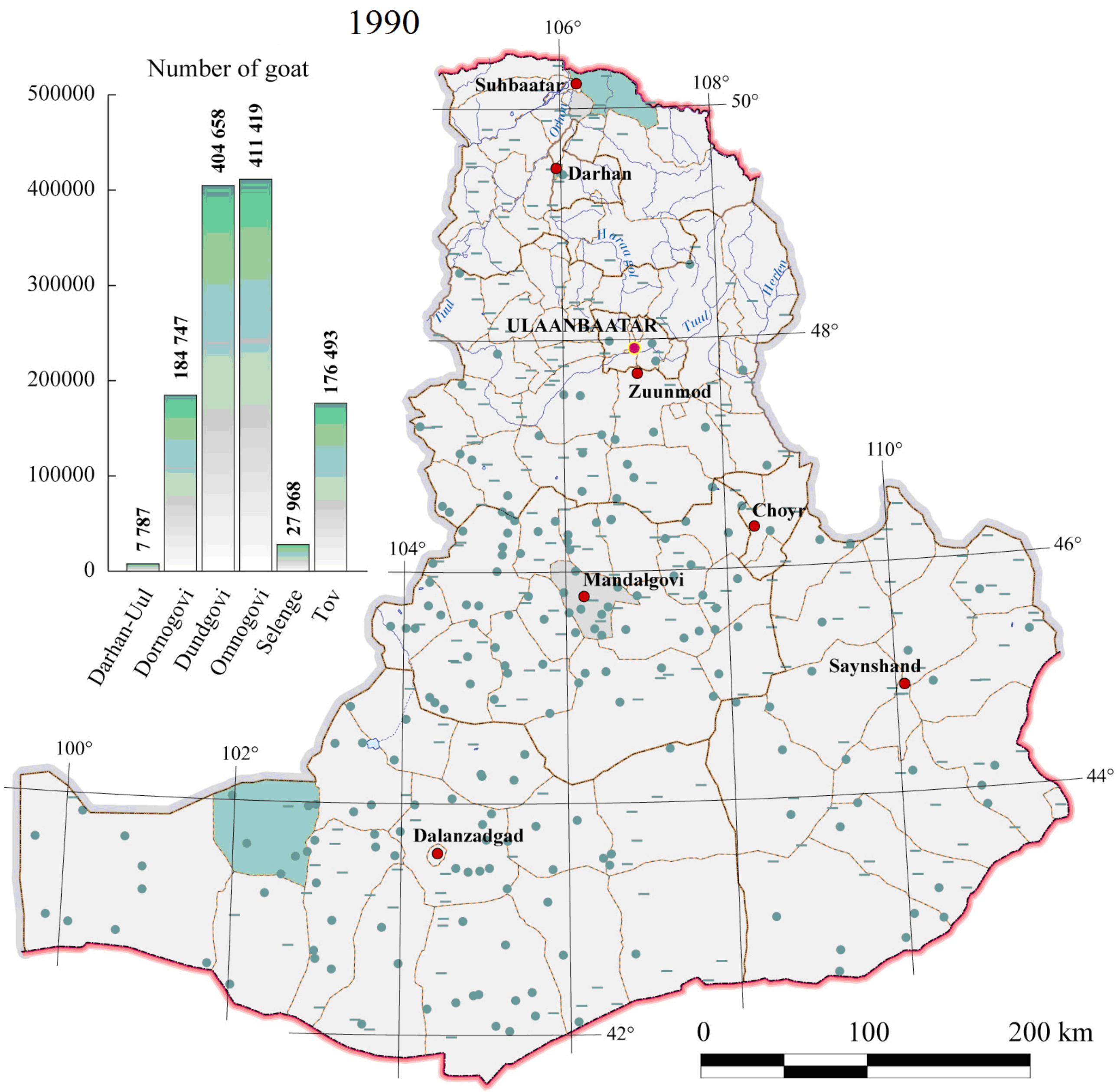


Fig. 4 a. Goat population density in the Central natural-economic region in 1990 (Ecosystems …, 2019).

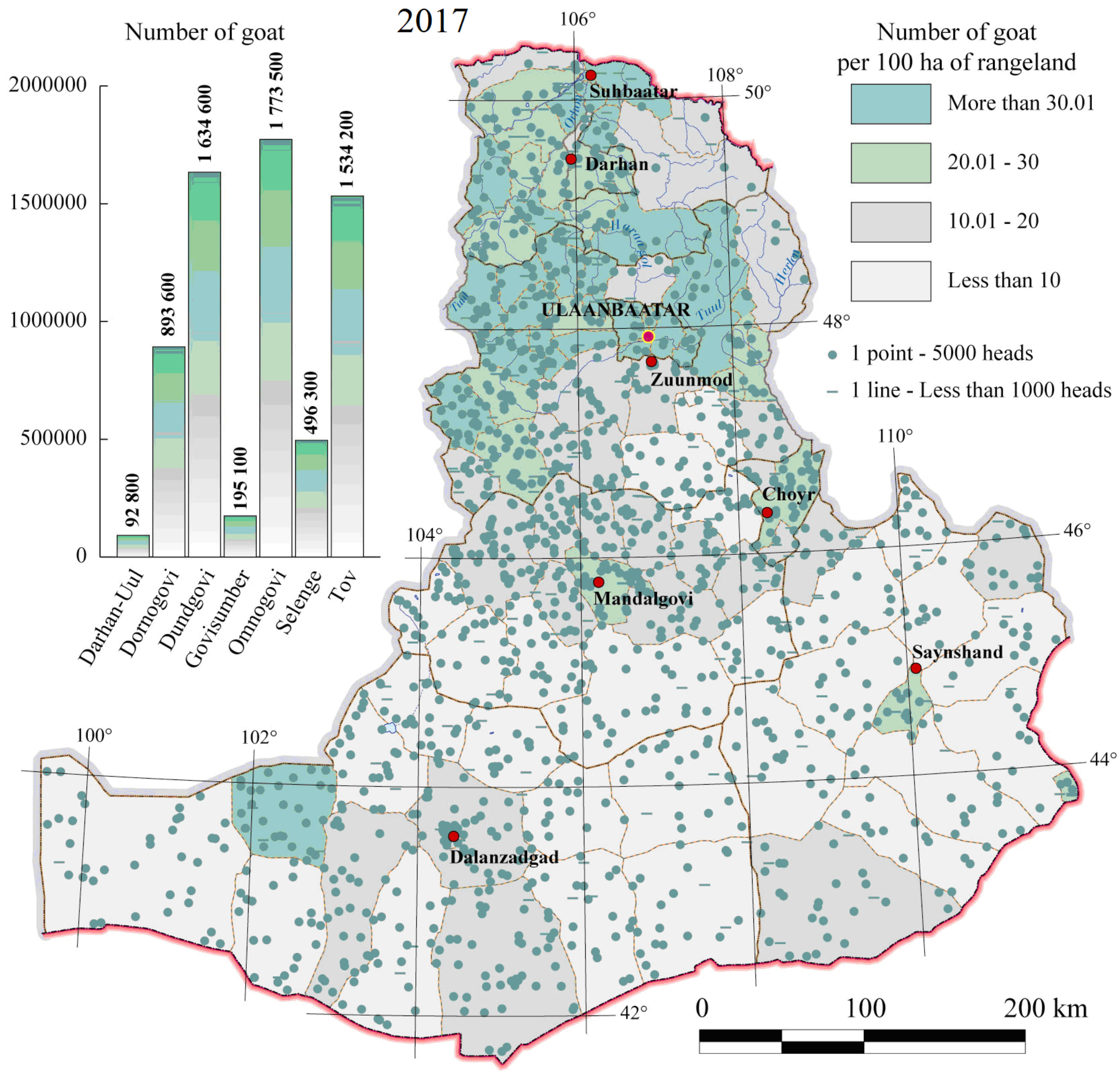


Fig. 4 b. Goat population density in the Central natural-economic region in 2017 (Ecosystems …, 2019).

The irrational pasture use during the period of increasing livestock numbers and frequent droughts resulted in the growth of amount of pasture lands with high and very high disturbance level, primarily including steppe ecosystems, the analysis of which is given below.

Traditionally the entirety of Mongolian livestock is supported by and provided with food right on the pastures year-round, although in fact some of the meadow and meadow-steppe ecosystems suitable for pastures are periodically used for hay harvesting to make a sparse feeding source for the times of fodder shortage, but the hay harvesting areas are small and permanent, mostly due to the climate fluctuations.

Results of Mongolian ecosystems' monitoring. In every NER for every type of ecosystem, which were defined as the result of mapping in 1989 (Ecosystems ..., 1995), the areas of 64 types were calculated by the level of their anthropogenic disturbance. The same calculations were also made on the basis of monitoring in 2012-2017 (Ecosystems ..., 2019). The results are shown in the synoptic regional tables 3 and 4. In these tables the 5 levels of anthropogenic disturbance of terrestrial ecosystems, used in the mapping of their condition (Methodical Guidelines …, 1989), were combined into 3: weak (very weak − I plus weak − II) with no significant anthropogenic changes; moderate (III); strong (strong − IV plus very strong − V), showing the native negative changes up to the irreversible ones.

In the tables the 64 types that are shown on the maps were combined into 12 zonal-belt and 1 azonal group of *hydromorphic* ecosystems (water-logged meadows and shrubs of highlands, forest and forest-steppe mountain belts, steppes and river floodplains, other floodplain meadows and bottom-land forests, as well as saline meadows and solonchaks of desert zone).

Highlands group is common for the main Mongolian mountain systems and combines cryophytic alpine ecosystems, highland tundra, Kobresia meadows and forests of dwarf birch. The last two are the most valuable and productive highland pastures.

Forest group is widespread in the north, in the mountains of Khuvsugul Region, Khentii and northern Khangai. It consists of mountain and mountain-valley forests, which are not classified by the forest-forming species and ecological features of habitats. The main reason of forest degradation is fires, usually caused by human, and the following cuttings.

Forest-steppe ecosystems present stable expositional combination of pseudo-taiga forests and meadow steppes, with lithophytic and moderately dry steppes. They make an altitudinal belt in low and middle mountains of Mongolian Altai, Khuvsugul Region, Khangai, Khentii, and northeast mountains.

Steppe ecosystems occupy the most part of Mongolia (more than 55% of its territory). They are the main productive all-seasonal and intensely exploited pastures, widespread throughout flat and mountainous territory, excluding desert far south, taiga north and the most of highlands. In the tables they are shown as 6 groups of ecosystems: highland steppes of the well-lit highland slopes of all the main mountain systems; meadow and moderately dry steppes, common for slopes of the most Mongolian mountains, excluding its desert south; dry and deserted steppes, common for lower mountains and sub-flat interfluve positions in the northwest of the wide western plains; desert steppes covering the most territories of the Gobi Valley of Lakes, the Great Lakes Depression, the southern half of the western plains, foothill and dry intermountain valleys of Gobi-Altai.

The 3 groups of *desert* ecosystems consist of steppe deserts (northern), true deserts (southern), and extremely arid deserts. They are mostly common for the plains, intramontane hollows and low mountains of Southern Mongolia, central parts of the Great Lakes Depression and the Gobi Valley of Lakes.

Northern deserts together with desert steppes form a unique zone of semi-deserts (Zhirnov et al., 2005) and are valued for their rich pastures.

The calculations show that from 1990 to 2017 the total area of terrestrial natural ecosystems in every natural-economic region significantly decreased, while the area of anthropogenic ecosystems increased. The biggest changes (reduction) of their areas were registered in the industrially developed Khangai and Central regions (by 1956.7 and 4487.8 km^2 respectively), but in the Western (456.6 km^2) and Eastern (178.1 km^2) regions the decrease is much lower.

For the past 30 years the difference between the total area of Mongolia and the area of its terrestrial natural ecosystems did never exceed 3.5%. Aside from the anthropogenic ecosystems (arable lands, industrial territories, construction sites, settlements), this difference also includes conditionally stable sizes of aquatic ecosystems, occupying about 1% or 16.1 thousand km^2.

The decrease of the natural ecosystems area is directly related to the expansion of territories with developed mining and residential areas (buildings, industrial zones, infrastructure), as well as plowed lands.

The areas of *anthropogenic* ecosystems increased by 6.83 thousand km^2 (35%). This includes the areas plowed up for agricultural use, which increased by 5.93 thousand km^2 (51.2%) in 2017 compared to 1989; and industrial ecosystems (developed mining and residential areas), which increased by

0.91 thousand km^2 (11.5%). The growth of anthropogenic ecosystems is perfectly shown on the maps of anthropogenic disturbance in the Selenge and Darkhan-Uul aimags as of 1990 and 2015 (fig. 5).

Table 3. Ratio between ecosystems areas in the Western and Khangai natural-economic regions by the degree of their anthropogenic disturbance in 1990 and 2017: 1 – weak, 2 – medium, 3 – strong.

Zonal-belt ecosystems groups	**Year**	**Western NER**				**Khangai NER**			
		Area							
		km^2	**% of Mongolia, by the rate of their anthropogenic disturbance**			**km^2**	**% of Mongolia, by the rate of their anthropogenic disturbance**		
			1	**2**	**3**		**1**	**2**	**3**
Highland	1990	27640.76	1.55	0.20	0.02	27685.73	1.69	0.08	0.00
	2017	**27645.1**	**1.55**	**0.18**	**0.03**	**27714.12**	**1.67**	**0.09**	**0.01**
Forest	1990	9715.23	0.58	0.04	0.00	63802.71	3.18	0.42	0.48
	2017	**9746.37**	**0.52**	**0.07**	**0.04**	**63645.01**	**2.75**	**0.93**	**0.38**
Forest-steppe	1990	8770.82	0.43	0.12	0.01	25682.1	0.92	0.65	0.07
	2017	**8749.19**	**0.36**	**0.16**	**0.04**	**25502.08**	**0.74**	**0.76**	**0.13**
Steppe, including:	1990	233548.29	11.65	2.89	0.39	169759.14	5.81	4.42	0.62
	2017	**233182.88**	**7.62**	**5.81**	**1.48**	**168612.79**	**4.47**	**5.18**	**1.13**
highland steppe	1990	11639.98	0.63	0.10	0.01	8432.71	0.51	0.03	0.00
	2017	**11567.84**	**0.56**	**0.16**	**0.02**	**8496.68**	**0.37**	**0.14**	**0.03**
meadow steppe	1990	6412.58	0.32	0.08	0.01	44643.15	1.09	1.47	0.29
	2017	**6408.93**	**0.25**	**0.13**	**0.04**	**44314.15**	**0.54**	**2.01**	**0.28**
moderately dry steppe	1990	35586.65	1.74	0.43	0.10	39496.04	0.94	1.34	0.25
	2017	**35633.61**	**1.13**	**0.92**	**0.22**	**38875.25**	**0.75**	**1.27**	**0.47**
dry steppe	1990	66286.85	2.98	1.13	0.13	25707.98	0.98	0.60	0.06
	2017	**66028.43**	**1.82**	**1.81**	**0.59**	**25450.93**	**0.62**	**0.79**	**0.22**
deserted steppe	1990	63190.11	3.23	0.69	0.12	23235.23	1.08	0.39	0.01
	2017	**63126.91**	**1.96**	**1.67**	**0.41**	**23237.58**	**0.85**	**0.52**	**0.12**
desert steppe	1990	50432.12	2.74	0.45	0.03	28244.03	1.20	0.59	0.02
	2017	**50417.16**	**1.90**	**1.12**	**0.20**	**28238.20**	**1.35**	**0.44**	**0.02**
Deserts, including:	1990	96922.45	5.54	0.62	0.04	46927.63	2.70	0.28	0.01
	2017	**96939.79**	**5.60**	**0.55**	**0.04**	**46935.88**	**2.69**	**0.30**	**0.01**
steppe deserts	1990	32489.19	1.51	0.53	0.04	14862.28	0.71	0.23	0.01
	2017	**32471.14**	**1.61**	**0.43**	**0.04**	**14865.88**	**0.71**	**0.24**	**0.00**
south deserts	1990	30161.82	1.83	0.09	0.00	15981.55	0.96	0.06	0.00
	2017	**30107.29**	**1.80**	**0.12**	**0.00**	**15981.84**	**0.95**	**0.07**	**0.00**
extremely arid deserts	1990	34271.44	2.19	0.00	0.00	16083.8	1.03	0.00	0.00
	2017	**34361.36**	**2.18**	**0.01**	**0.00**	**16088.16**	**1.03**	**0.00**	**0.00**
Hydromorphic	1990	25482.36	0.79	0.71	0.13	40543.4	1.22	1.14	0.23
	2017	**25359.96**	**0.72**	**0.62**	**0.28**	**40054.16**	**0.80**	**0.77**	**0.99**
Total area of NER ecosystems	1990	402079.9	20.5	4.6	0.6	374400.71	15.52	7.00	1.42
	2017	**401623.3**	**16.4**	**7.4**	**1.9**	**372464.04**	**13.12**	**8.03**	**2.65**

Table 4. Ratio between ecosystems areas in the Central and Eastern natural-economic regions by the degree of their anthropogenic disturbance in 1990 and 2017: 1 – weak, 2 – medium, 3 – strong.

Zonal-belt ecosystems groups	Year	Central NER				Western NER			
		Area							
		km^2	% of Mongolia, by the rate of their anthropogenic disturbance			km^2	% of Mongolia, by the rate of their anthropogenic disturbance		
			1	2	3		1	2	3
Highland	1990	972.63	0.06	0.00	0.00	398.25	0.02	0.00	0.00
	2017	**972.66**	**0.06**	**0.00**	**0.00**	**122.03**	**0.01**	**0.00**	**0.00**
Forest	1990	30928.54	0.81	0.26	0.91	14183.1	0.31	0.11	0.48
	2017	**30471.01**	**0.85**	**0.59**	**0.51**	**14075.87**	**0.34**	**0.23**	**0.33**
Forest-steppe	1990	7717.56	0.16	0.26	0.07	10028.97	0.55	0.09	0.00
	2017	**7217.28**	**0.12**	**0.21**	**0.13**	**8200.79**	0.31	0.13	0.08
Steppe, including:	1990	233659.66	8.35	5.51	1.08	228860.39	12.85	1.44	0.34
	2017	**230886.93**	**5.53**	**6.70**	**2.53**	**230893.7**	**7.32**	**5.53**	**1.91**
highland steppe	1990	158.45	0.01	0.00	0.00	–	–	–	–
	2017	**158.18**	**0.01**	**0.00**	**0.00**	**–**	**–**	**–**	**–**
meadow steppe	1990	24033.75	0.51	0.89	0.14	35472.87	2.19	0.08	0.00
	2017	**22892.92**	**0.30**	**0.81**	**0.35**	**35430.75**	**1.78**	**0.44**	**0.05**
moderately dry steppe	1990	40463.28	0.34	1.71	0.54	70168.05	4.09	0.31	0.09
	2017	**38583.71**	**0.28**	**1.36**	**0.83**	**70438.75**	**2.21**	**1.70**	**0.59**
dry steppe	1990	29424.52	0.80	0.89	0.19	115645.86	6.13	1.00	0.26
	2017	**29431.03**	**0.20**	**0.99**	**0.70**	**115646.08**	**2.93**	**3.24**	**1.23**
deserted steppe	1990	45381.08	1.87	0.90	0.13	7569.93	0.44	0.04	0.00
	2017	**45445.94**	**0.57**	**1.90**	**0.43**	**9374.46**	**0.41**	**0.15**	**0.04**
desert steppe	1990	94198.58	4.82	1.13	0.07	3.68	0.00	0.00	0.00
	2017	**94375.15**	**4.18**	**1.64**	**0.21**	**3.66**	**0.00**	**0.00**	**0.00**
Deserts, including:	1990	163521.6	9.40	1.04	0.01	–	–	–	–
	2017	**163409.68**	**9.20**	**1.21**	**0.04**	–	–	–	–
steppe deserts	1990	81235.49	4.26	0.92	0.01	**–**	**–**	**–**	**–**
	2017	**81202.53**	**4.20**	**0.96**	**0.03**	–	–	–	–
south deserts	1990	77152.94	4.81	0.12	0.00	**–**	**–**	**–**	**–**
	2017	**77079.98**	**4.66**	**0.26**	**0.01**	–	–	–	–
extremely arid deserts	1990	5133.17	0.33	0.00	0.00	**–**	**–**	**–**	**–**
	2017	**5127.17**	**0.33**	**0.00**	**0.00**	–	–	–	–
Hydromorphic	1990	30711.07	1.16	0.46	0.34	27271.21	0.34	0.58	0.82
	2017	**30065.7**	**0.98**	**0.50**	**0.44**	**122.03**	**0.34**	**0.58**	**0.82**
Total area of NER ecosystems	1990	467511.05	19.94	7.54	2.40	14183.1	14.07	2.21	1.65
	2017	**463023.26**	**16.74**	**9.22**	**3.64**	**14075.87**	**8.33**	**6.47**	**3.14**

For the *arable lands* mostly the fertile dark-chestnut and chestnut steppe soils were used in the river and dry intermountain valleys, intramontane hollows and plains in the northern half of the country (photo 4). At the turn of the XX and XXI centuries large areas of arable lands were abandoned, especially in southern, central, and western Mongolia. In 2017, according to the mapping data (Ecosystems…, 2019), 17,491.26 km^2 of lands, mostly steppe ones, were plowed up with old and new arable lands and multi-aged fallows among them. For example, in the Selenge and Darkhan-Uul aimags the plowed lands increased twice by 2015 in comparison to 1990 (5538.86 km^2 and 2750.95 km^2; fig. 5 a, b).

Plowing activities totally destroyed a natural vegetation cover of ecosystems and made soil and biocenosis-forming processes develop anthropogenically. The main diagnostic signs of soil degradation in the strongly disturbed dry lands are dehumification, fine-grained sediment loss in the plough layers, and sandiness intensification in the surface layers. Extent of these processes in every type of chestnut soil depends on the location of plowed fallow lands in different landscapes, and can be determined by lithological soils composition and their disposition in relation to the wind regime. The most significant signs of dehumification (up to 50-60%) and fine-grained sediment loss (up to 40-50%) are common for ecosystems with chestnut soils of light particle size distribution (i.e. sandy and sandy-loam) in the landscapes of moderately dry steppes. Moreover, all rubbly soils differ by the "gammadisation" of their surface, which decreases water potential of the landscapes of dry steppes (Nyamsambuu, 2004; Khadbaatar, 2010; Bazha et al., 2018).

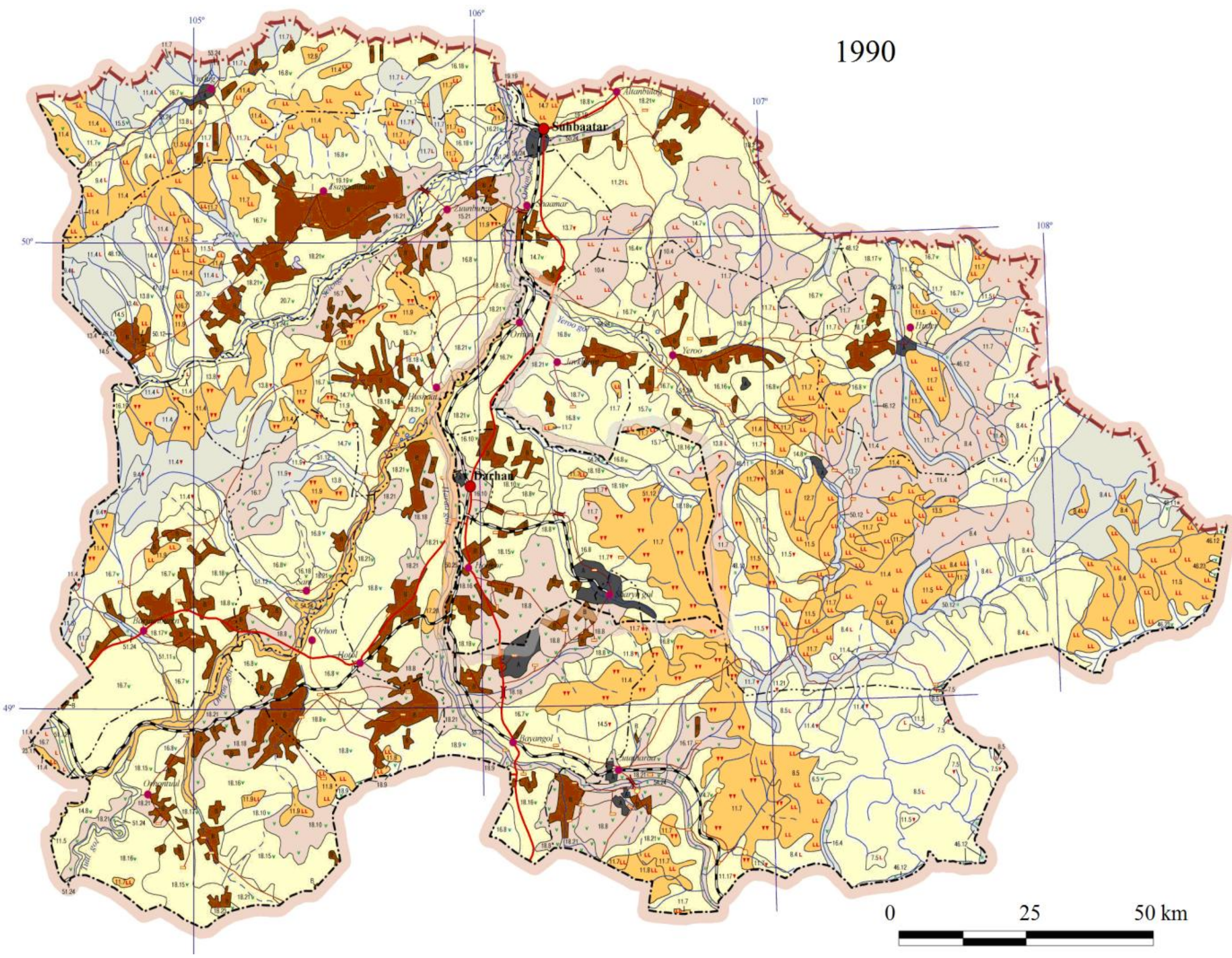


Fig. 5 a. Map of anthropogenic disturbance of the Selenge and Darhan-Uul aimags ecosystems in 1990. *Legend:* brown − arable land, gray − settlements and mining activities (Ecosystems …, 2019).

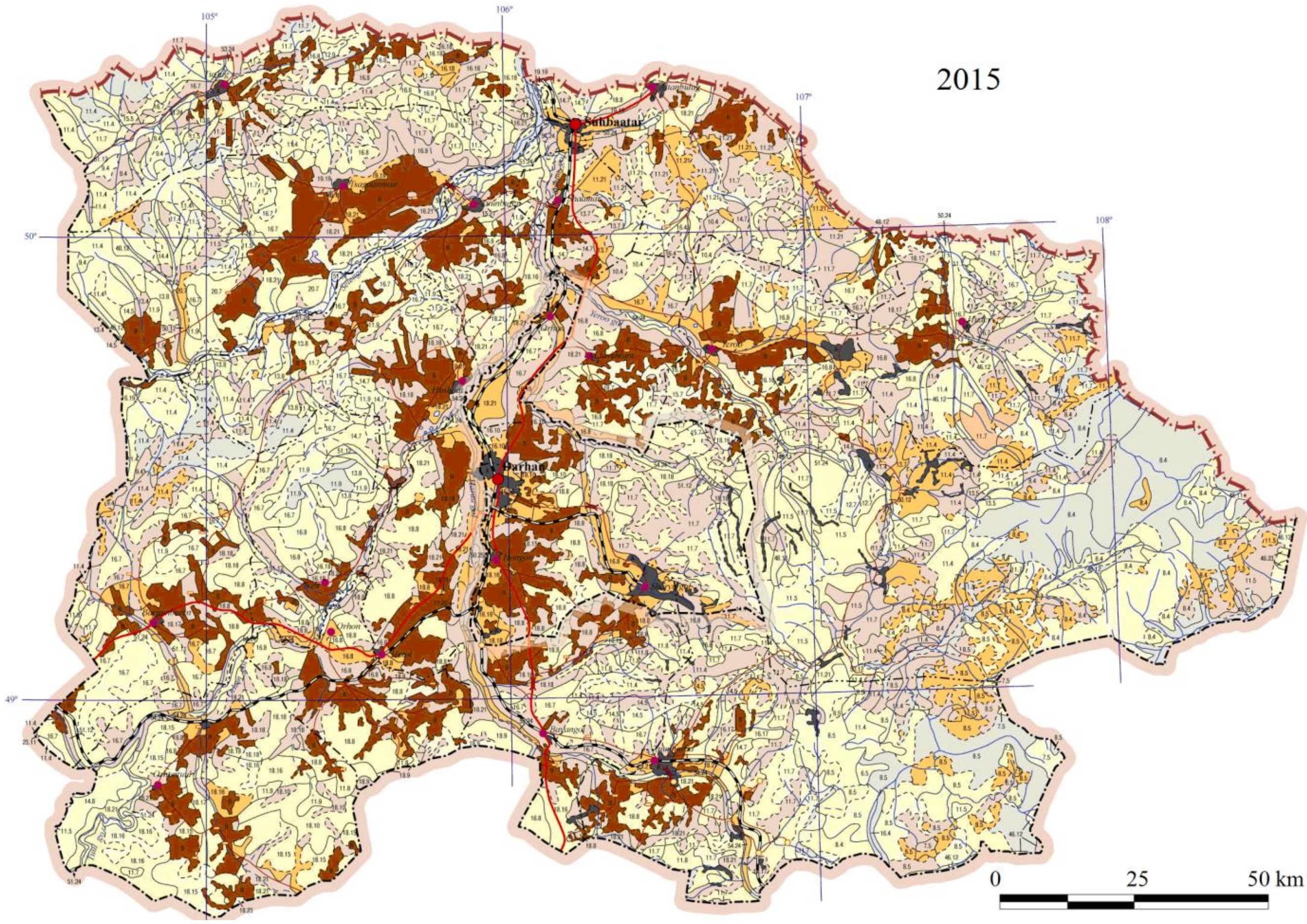


Fig. 5 b. Map of anthropogenic disturbance of the Selenge and Darhan-Uul aimags ecosystems in 2015. *Legend:* brown − arable land, gray − settlements and mining activities (Ecosystems …, 2019).

Those old fallows which have enough available forage are often used for livestock grazing, which in its turn also interferes with the normal restoration of zonal vegetation. In recent years the fallow lands are being used again as intended. Moreover, the new available lands are being plowed in steppe valleys of the forest-steppe belt.

During the study period the areas of *industrial* ecosystems grew by 11.5%. Numerous small gold mining sites appeared in Khentii, Khangai, and other mountainous territories, as well as in river valleys and desert hummocks (Kosheleva et al., 2015; Kasimov et al., 2016). The most abundant mining sites were found in the Selenge aimag, as shown on the maps of anthropogenic disturbance (fig. 5 a, b). The large coal deposits have been developed in the south and other regions of Mongolia, the sites of iron and polymetallic ores mining have been expanded, and the large oil production is developing in the east (photo 5).

The growth of urban population had inevitably caused expansion of residential territories. It is especially noticeable around large industrial centers, where the main internal migration was heading: the territory of Ulaanbaatar expanded more than twice (from 414.2 to 903.6 km^2), Darkhan − more than 8 times (from 6.7 to 65.8 km^2), Erdenet (plus adjoining mining sites for polymetallic ores and related activities) − more than 10 times (from 8 to 81 km^2; photo 6). Territories of some aimag centers had noticeably increased: Murun, Bulgan, Altai, Bayanhongor, Zuunmod, Choir, Dalandzadgad, and others.

The table 5 shows relative data for the areas of zonal natural ecosystems for Mongolia in total; they are differentiated by the level of their anthropogenic disturbance, according to the mapping of 1990 and 2017.

Photo 4. Narrow forest-steppe intermountain valleys are plowed up for cereal (Selenge aimag).

Photo 5. Industrial ecosystem (abandoned coal mine) in the Dundgovi aimag.

Forest ecosystems are an integral part of natural-territorial complexes of Mongolia, as the forest industry plays a significant role in the country economics.

Since 1990 the total forest area has decreased by 0.58% (from 118,629.58 to 117,938.30 km^2), mostly due to the new anthropogenic structures, and partially due to the cutting and severe fires (photo 7).

Forest fires are the main reason of native forest destruction and transformation of the forest ecosystems' composition, however the dynamic trends of forest condition are ambiguous. The area of strongly disturbed forest ecosystems decreased, which can be explained primarily by the fact that forests, destroyed in the past on vast territories and replaced with burned-out forests sites or just severely damaged by fires, had mostly restored by 2017. Thus, the secondary small-leaved (consisting mostly of *Betula pendula*[1]) and mixed forests appeared in the west and middle-mountains of Khentii, in the mountains east of Khentii and in the east and northwest of Khangai; while in the center, west and north of Khangai and central Khentii the native coniferous species (*Larix sibirica*, *Pinus sibirica*) started to restore (Dorzhsuren, 2009; Dulamsuren et al., 2010; Yarmishko et al., 2010; Danilin, Tsogt, 2012; Tushigmaa, 2012; Zoyoo, 2013; Undraa et al., 2015; photo 8-10). Recently the main seats of forest fires have moved to the east of Khuvsugul Region, into the northwest of Khentii and to the ridges adjoining Russian territory: Buteeliin, Dzhidinsky, Baldzhinsky, Eren Daba, etc. There the native larch and pine forests burn together with the secondary small-leaved ones. On the early stage self-restoration of these forests goes through a long and derivative small-leaved and shrubby successions with *Prunus pedunculata*, *P. sibirica, Spiraea aquilegifolia, S. media, Betula fruticosa*, *Dasiphora fruticosa,* and others (Bazha et al., 2019; photo 11). By 2017 the areas of slightly disturbed Mongolian forests reduced by 5.2%, but forests with moderate anthropogenic disturbance increased by 13.2%. The strongly disturbed forest ecosystems decreased by 8% due to the reducing areas of cutting, severe fires, natural self-restoration of the previously burnt forests and amounts of wood harvesting.

Photo 6. New districts of Ulaanbaatar city.

To obtain objective qualitative and quantitative data about reducing areas of the native coniferous forest and their replacement with derivative one, another thorough study is needed, since we monitored the ecosystems only within the separate types that we recorded in 1989.

Assessment of *forest-steppe* ecosystems is integral. The condition of a natural combination of forest massifs and steppes can be opposite; forests can be burnt out, or replaced by secondary ones, or cut down,

[1] Latin names are given according to “The Global Biodiversity Information Facility” (2001).

or destroyed by insects, while steppes can be in a background state; or, on the contrary, forests can be intact, while steppes can be heavily overgrazed. The assessment of the anthropogenic disturbance level in the forest-steppe ecosystems shows that the slightly disturbed ecosystems decreased by 16.7%, while the moderately and severely disturbed ones increased by 4 and 7% respectively. The total area of forest-steppe decreased by 10% for the same reasons as the forest area. Constant livestock grazing on the burned forest areas led to the complete disappearance of some small islands of forests on the southern periphery of the forest-steppe belt (Khishigjargal et al., 2013; photo 12).

Table 5. Percentage ratio between areas of zonal-belt ecosystems' groups of Mongolia by the degree of their anthropogenic disturbance: 1 – weak, 2 – medium, 3 – strong (% of the country's area).

Zonal-belt ecosystems groups	**1990**					**2017**				
	Area									
	Total		**by the rate of its anthropogenic disturbance**			**Total**		**by the rate of its anthropogenic disturbance**		
	km^2	**%**	**1**	**2**	**3**	**km^2**	**%**	**1**	**2**	**3**
Highland	56697.37	3.62	3.32	0.28	0.02	56453.91	3.61	3.30	0.27	0.04
Forest	118629.58	7.59	4.89	0.83	1.87	117938.30	7.54	4.46	1.82	1.26
Forest-Steppe	52199.45	3.33	2.06	1.12	0.15	49669.34	3.17	1.53	1.26	0.38
Steppe, including:	865847.48	55.35	38.64	14.26	2.45	863576.30	55.21	24.96	23.20	7.04
highland steppe	20231.14	1.29	1.15	0.13	0.01	20222.70	1.29	0.94	0.30	0.05
meadow steppe	110562.35	7.07	4.11	2.52	0.44	109046.75	6.97	2.87	3.39	0.72
moderately dry steppe	185714.02	11.87	7.11	3.79	0.98	183531.32	11.73	4.37	5.25	2.11
dry steppe	237065.21	15.16	10.89	3.63	0.64	236556.47	15.12	5.56	6.82	2.74
deserted steppe	139376.35	8.91	6.62	2.02	0.26	141182.89	9.03	3.79	4.24	1.00
desert steppe	172878.41	11.05	8.76	2.17	0.12	173034.17	11.06	7.43	3.20	0.43
Deserts, including:	307371.68	19.65	17.65	1.94	0.06	307285.35	19.64	17.49	2.06	0.09
steppe deserts	128586.96	8.22	6.48	1.68	0.06	128539.55	8.22	6.52	1.63	0.07
south deserts	123296.31	7.88	7.61	0.27	0.00	123169.11	7.87	7.41	0.45	0.01
extremely arid deserts	55488.41	3.55	3.55	0.00	0.00	55576.69	3.55	3.54	0.01	0.00
Hydromorphic	124007.8	7.93	3.92	3.13	0.88	122751.03	7.84	2.84	2.47	2.53
Total for Mongolia	1524753.36	97.5	70.5	21.6	5.4	1517674.23	97.0	54.6	31.1	11.3

The areas and state of *highland* ecosystems did not change much; its total area decreased by 0.55% or 243.46 km^2. The area of severely disturbed ecosystems increased the same way, primarily due to the decreasing highland ecosystems with a slight anthropogenic disturbance. More and more livestock started grazing on the highland pastures of Khangai and Mongolian Altai, mostly on the mountain meadows (with Kobresia, sedge, mixed-grass-cereals) and mountain-tundra forests with dwarf birch and sedge-Kobresia (Ogureeva et al., 2012; Ogureeva, 2015; photo 13).

Photo 7. Felling of a burned larch forest (Bulgan aimag).

Photo 8. Secondary birch forest (*Betula pendula*) on the site of a burnt pinery (Selenge aimag).

Steppes are the most important natural ecosystems for the economy of Mongolia because they are the primary fodder source of the main branch of local agriculture, i.e. livestock grazing. Despite the fact that from 1990 to 2017 the total steppes area decreased just slightly, only by 0.27%, the ratio between steppe ecosystems with various levels of anthropogenic disturbance changed a lot. The slightly disturbed steppes decreased by 35.3%, while the moderately disturbed ones increased by 63%. The heavily disturbed areas expanded almost 3 times up to 60,795.77 km^2. These changes are registered for all regions and for all zonal-belt groups of steppe ecosystems (table 6). The strongest negative transformations of pastures are registered for the most valuable fodder steppes (moderately dry, dry, and deserted), which cover 36% of the Mongolian territory. The average reduction of the slightly disturbed steppe ecosystems is 22.4%. The highly disturbed area increased by 7%, the moderately disturbed one − by 15.4%.

Photo 9. Grassy pine forest after a wildfire (Selenge aimag).

Photo 10. Scorched remains in a place of a burnt and cut down pseudo-taiga larch forest (Arkhangai aimag).

Photo 11. Recovering shrub succession of *Prunus sibirica* on the site of a burnt pinery (Selenge aimag).

Photo 12. Mountain forest-steppe (Bulgana aimag).

The main form of steppe degradation is pasture digression caused by excessive pasture loads, which are the result of uncontrollably growing numbers of livestock, increasing sizes of herds, and minimization of their species composition, as well as disturbance of the traditional and time-tested system of pasture usage. However, even the slight loads show signs of degradation when vitality of the main cenosis-forming steppe species gets suppressed: *Agropyron cristatum, Achnatherum sibiricum, Agrostis vinealis, Carex pediformis, Cleistogenes squarrosa, Festuca lenensis, F. sibirica,* *Helictochloa hookeri, Koeleria macrantha, K. glauca, Poa attenuata, Stipa baicalensis, S. krylovii, S. tianschanica, S. Caucasica,* etc. The moderate loads cause changes in the dominant species composition, decrease of phytocenotic features (such as species composition, projective cover, productivity), while the strong and very strong ones create transformed, depleted and mono-dominant communities with low numbers of species, shaped by invasive and digressively active species: *Allium polyrhizum, Artemisia anethifolia, A. adamsii, A. frigida, A. laciniata, Carex duriuscula, Chenopodium acuminatum, Ephedra sinica, Peganum nigellastrum, Potentilla cinerea, Sibbaldianthe bifurca, Thermopsis lanceolata, Iris lacteal,* etc. (Danzhalova, 2008; Gunin et al., 2012; Ariunbold, 2014; Tuvshintogtokh, 2014; Bazha et al., 2015; Kazantseva et al., 2015; Urtnasan, Lyubarskiy, 2015; Safronova, Narantuya, 2016; Petukhov et al., 2018; Structute …, 2018; photo 14, 15).

Photo 13. Alpine Kobresia pasture (Arkhangai aimag).

Significant destructive transformations of pasture ecosystems are registered in the steppe zone, steppe and forest-steppe belts of Central Mongolia (Bulgan, Orkhon, Selenge, Darkhan-Uul, Ovorkhangai, Tuv, Khentii, and Dundgovi aimags), in the valleys, intermountain hollows and plateaus of Khangai and Gobi-Altai and in the west of Mongolian Altai, as well as on the steppe pastures (including desert steppes) of the Great Lakes Depression and the Valley of Lakes. The areas of heavily overgrazed pastures around aimag centers grew significantly bigger, as well as ones that were moderately and strongly degraded due to the pasture overloads in the highland steppe pastures of Khangai and Gobi-Altai (photo 16).

The largest degradation is recorded for steppe pastures (meadow, moderately dry, dry, and deserted). Psammophytic steppes are the most overgrazed due to livestock grazing and mechanical activities (photo 17, 18). In Mongolia these steppes occupy about 3.5% of the area covered with steppe plants. According to the mapping data, by 2017 the area of highly disturbed steppes of this kind increased by 8.6 times (up to 6,817 km^2) in comparison with 1990, and the moderately disturbed grew by 12%.

The highland and meadow steppes have similar dynamics of anthropogenic disturbance. The areas of slightly disturbed steppes decreased by 16-17%, the moderately disturbed increased by 12.5-13%, and strongly disturbed grew by 3-4.5%. It means that pasture digression moves into the upper mountain belts.

Table 6. Changes in anthropogenic disturbance of steppe ecosystems since 1990 to 2017.

Zonal-belt ecosystems groups	Anthropogenic disturbance rate (% of the total area of zonal-belt groups)		
	Weak	Medium	Strong
highland steppe	-16.2	+13.1	+3.1
meadow steppe	-16.9	+12.6	+4.3
moderately dry steppe	-22.9	+13.1	+9.8
dry steppe	-34.2	+20.1	+14.1
deserted steppe	-32.3	+24.2	+8.1
desert steppe	-12.1	+9.3	+2.8

Photo 14. Degraded pasture with a monodominant plant community of *Artemisia frigida* (Selenge aimag).

Desert steppes did not undergo any significant destructive changes, and some of the desert-steppe pastures even started to restore due to the pasture loads being reduced.

Level of anthropogenic disturbance of *desert* ecosystems did not change much (photo 19). The area of the slightly disturbed deserts decreased by 0.8%, the area of the moderately and strongly disturbed ones increased by 0.6 and 0.2% respectively. The negative changes in the deserts condition are mostly caused by the large mining sites, and therefore by high demand of livestock products and cattle constantly gathering on pastures around the mining sites.

Hydromorphic ecosystems combine some groups of ecosystems, the functioning of which is related to the leading role of high moisture (soil moisture accumulated seasonal, floodplain, stagnant, etc.). Trends of changes in the level of anthropogenic disturbance in various hydromorphic ecosystems of mountains and plains (meadow, trees and shrubs, solonchaks, saline soils) are similar. The slightly and moderately disturbed ones decreased by 13.2 and 8.0%, the strongly disturbed ones decreased significantly by 21.2%, mostly due to the growing pasture load on the hydromorphic ecosystems of the river valleys (Zoyoo et al., 2014).

Photo 15. Extremely overgrazed dry steppe with *Artemisia adamsii* (Central aimag).

Photo 16. Strong pasture digression of psammophytic desert steppe (Omnogovi aimag).

Ecosystems monitoring on the key sites. The large-scale studies of ecosystems on the key sites, somons, and model testing plots in various natural regions of Mongolia under impact of different anthropogenic factors are highly important to understand the ways these factors affect various terrestrial ecosystems, and to thoroughly study their degradation dynamics. One of these territories is a "Shamar" key site (52.7 km^2) located in the Selenge aimag, which borders Russian territory. The site is interesting for a detailed study of how a replacement of native pine forests with derivative ones and shrubs successions goes.

Photo 17. Psammophytic steppe with strong pasture digression and water erosion (Selenge aimag).

Photo 18. Dry psammophytic steppe degraded by overgrazing (Bulgan aimag).

Photo 19. North deserts ecosystems (Omnogovi aimag).

Over the study territory we have classified 42 natural and 3 anthropogenic ecosystems (fig. 6). In its northwestern part sand dunes are occupied with pine forests on the weak sandy soils common for pine forests. To east and south the dunes are replaced by the gentle wavy plains with sparse pine forests and meadow steppes on the dark-chestnut soils, and sometimes the old fallows can be found. Further to the east the gentle hilly plains are covered with secondary grassy birch forests and aspen forests with old, sparsely standing pine trees on the dark-chestnut soils. Above 900 m on the granites eluvium the rubbly dark-chestnut soils have formed under the mixed-grass-cereals steppe apricot forests with the remains of dead pine trunks. Below, on the northwestern aspect a mass of loess-like pure sandy loams with thick and well-developed cover of *Prunus sibirica*.

According to the data from that key spot, the flat areas, which were covered with pine forest before the fires, usually restore their forests, but the native species change (pine is replaced with birch and aspen), and mountain slopes viewing the Selenge River valley and intermountain hollows turn into shrubs formed by *Prunus sibirica*, which do not allow pine to restore. The evidence of the previously widespread pine forests are the survived fragments of apricot pine forests or apricot forests with sparse pine trees. An important sign of expanding apricot area is this species' intrusion and successful development in the forest communities on the slopes with northern aspect (Bazha et al., 2018).

As the results showed, the slightly disturbed ecosystems occupy about 24.1% of the key spot area, moderately disturbed occupy 19.87%, strongly disturbed − 41.54%, and very strongly disturbed − 14.5% (fig. 6). This knowledge helped a lot to improve the methods to assess ecosystems condition, as well as to carry out the monitoring and small-scale mapping of the current ecosystems condition in Mongolian aimags.

Conclusions

Compilation of the "Ecosystems of Mongolia" atlas (2019) was a natural mapping result of a big phase in the long-term studies of the terrestrial natural ecosystems of Mongolia, carried out by the Russian and Mongolian researchers as part of the CRMCBE Scientific Program.

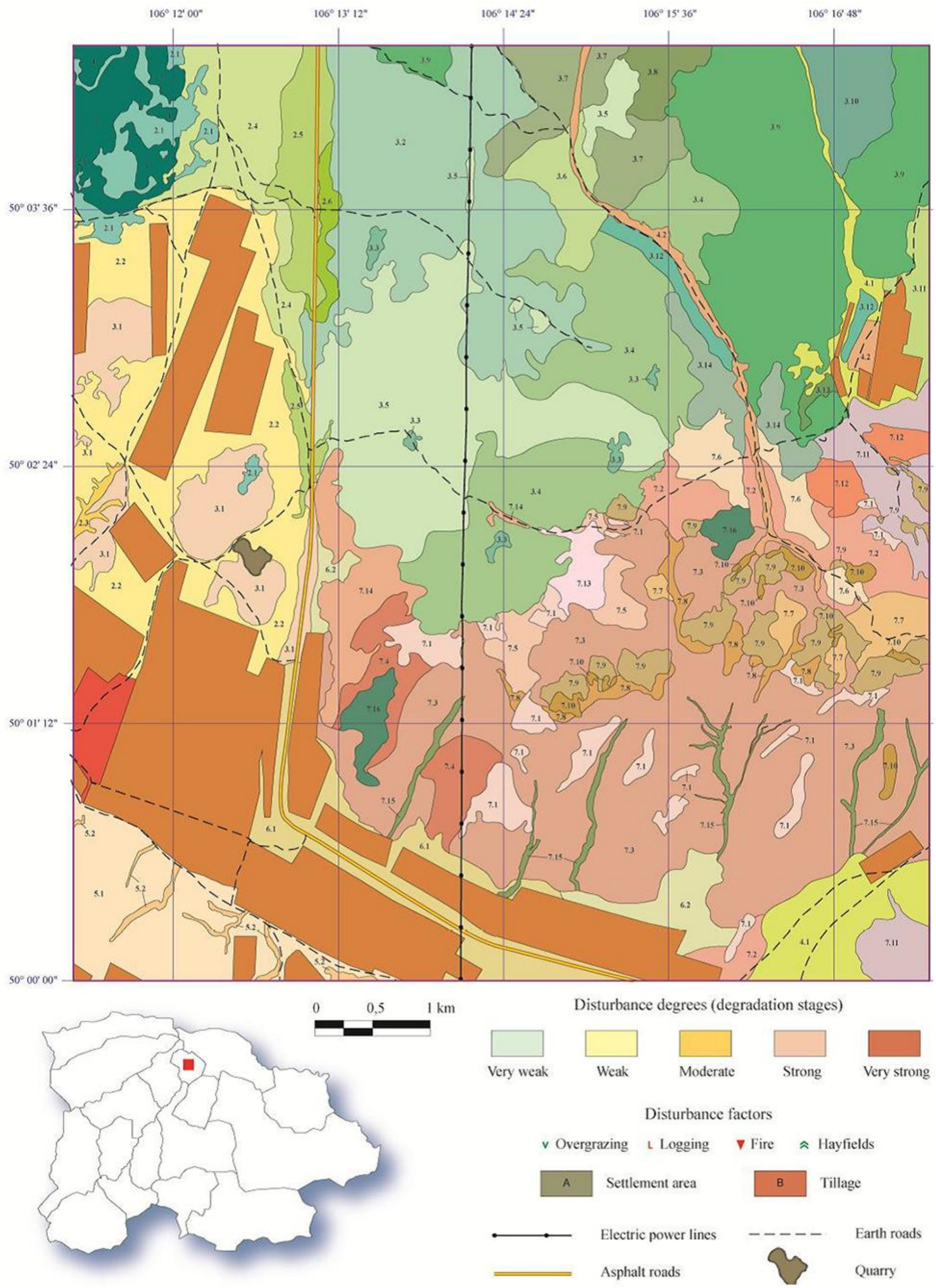


Fig. 6 a. Map of the "Shamar" key plot ecosystems in 2014 (Ecosystems ..., 2019).

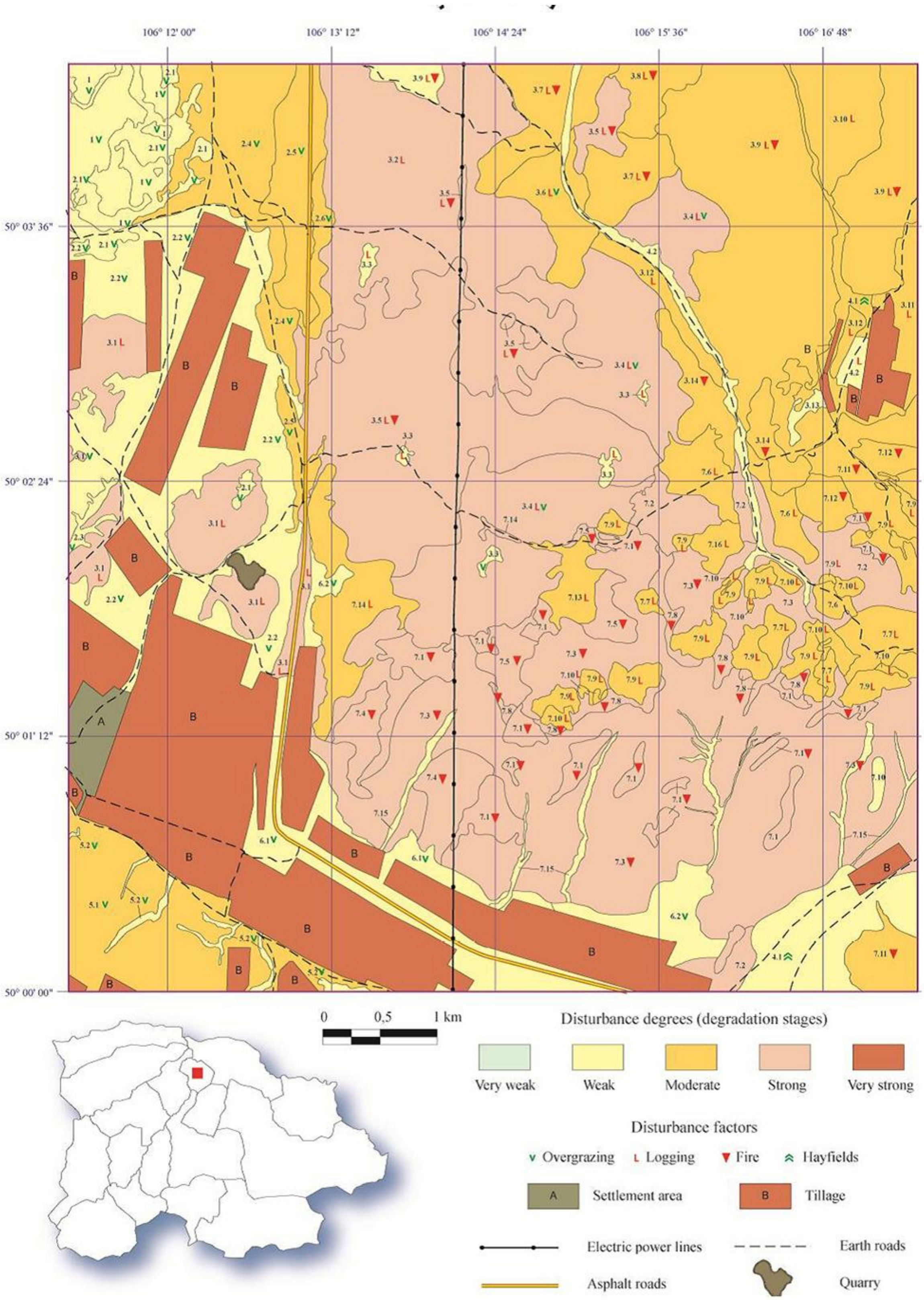


Fig. 6 b. Map of the anthropogenic disturbance of the "Shamar" key plot ecosystems in 2014 (Ecosystems ..., 2019).

Among other things, it summed up the works on inventory of ecosystems and monitoring of their condition carried out 25-27 years after the first similar researches were done. As a result, the main anthropogenic factors that affected ecosystems negatively up to their total degradation, were determined; the scale of anthropogenic disturbances was established, and the areas and location of natural ecosystems with different disturbance levels and anthropogenic ecosystems were identified.

The comparative analysis of the ecosystems conditions in 1989-1990 (Ecosystems ..., 1995) and 2017 (Ecosystems ..., 2019) carried out on the basis of the field and calculation data, unequivocally shows that degradation processes became stronger in the terrestrial natural ecosystems of Mongolia for the period said. The areas of background and mildly disturbed ecosystems decreased mostly by 1/3, the moderately disturbed ones increased by 44%, and the strongly and very strongly disturbed ones increased more than twice. The same picture can be seen in the ecosystems suitable for pastures; their total area decreased only by 0.4%, however, the amount of mildly disturbed ones reduced almost by 1/4, of moderately disturbed − more than by 43%, and the strongly disturbed increased almost three times, or by 188%.

The main reasons of anthropogenic disturbance in ecosystems are as follows:

- pasture digression that is still progressing since 1990 and has grown stronger over more than 1/3 of the country,
- forest wildfires that destroyed about half of the native coniferous forests by 2017, which now are mostly replaced by the secondary small-leaved trees,
- spread of anthropogenic ecosystems at the expense of total destruction of the natural complex, made of soil and vegetation cover, microrelief (and sometimes mesorelief), and zoocenoses.

By 2017 the area of anthropogenic ecosystems took 1.68% of Mongolian territory, therefore growing by 40% since 1990. The area of plowed lands (arable lands and multiple-aged fallows) increased more than by half, now covering 1.12% of the country territory; while the industrial (developed mining areas, industrial facilities) and residential ecosystems occupy 0.56% or 8.8 thousand km^2. Moreover, the network of asphalt and spontaneous dirt roads has grown abruptly, although we could not take their area into account due to the scale of our mapping.

The progressing degradation of natural ecosystems was also registered in the special protected natural areas (SPNA), such as nature reserves, national parks, and state wildlife sanctuaries. This degradation is caused not only by forest wildfires, but also by uncontrolled livestock grazing since the laws of Mongolia do not forbid grazing on the territories of the most SPNA.

Pasture digression has especially affected the ecosystems with psammophytic vegetation (of steppe and deserts) located on sandy soils and sands and distributed over 96,008.5 km^2 (which is about 6% of Mongolian territory). Among them the area of the strongly disturbed ones was just 1% in 1990, but grew 8 times by 2017; the area of the moderately disturbed increased by 12%.

Pasture degradation is registered on the vast territory and affects the most important and traditional field of Mongolian economy − livestock grazing. According to the atlas data, the territories with a strong pasture digression, registered in 1989, have mostly become centers for further degradation of pasture ecosystems. The steppe ecosystems of the most populated Mongolian territories had the highest pasture loads: Tuv, Selenge, and Bulgan aimags. The steppe pastures were also highly overloaded in the north of Dundgovi and the south of Khuvsgul aimags, in the valleys of Kherlen and Ider Rivers, the intramontane valleys and hollows of Khangai, Gobi-Altai and southern Mongolian Altai. The semi-desert pastures were digressed the most on the foothill plains of Gobi and Mongolian Altai (in Govi-Altai, Bayankhongor, and Umnugovi aimags), in the north of Dornogovi aimag, in the Valley of Lakes (Bayankhongor aimag), and around lakes of the Great Lake Depression (Khovd and Govi-Altai aimags).

By 2017 the area of strongly disturbed pastures on these territories grew even wider. Severe pasture digression had spread from intermountain valleys and central parts of hollows into foothill steppe valleys, slopes of low mountains and hummocks, surroundings of every settlement and mining facilities, valleys and nearby steppe slopes of the large rivers, such as Selenge, Delger moron, Ider, Chuluut, Orkhon, Tuul, Kharaa, Yoroo, Kherlen, Khovd, Tes, Zavkhan, and Khungui.

The information of the "Ecosystems of Mongolia" atlas (2019) helps with assessing risks for the natural-territorial complexes and economy of Mongolia caused by modern forms, methods, and amounts of anthropogenic impact that natural ecosystems have to endure. The atlas allows us to make all the necessary calculations to plan the nature protection events, while taking into account already identified trends of changes in the ecosystems, as well as to develop some economic projects for nature protection. The information in the atlas can be useful for administrative, projecting, and nature protection structures of Mongolia, for industrial and social organizations.

The atlas clearly shows versatility and scale of the long-term scientific researches carried out by the research team of Russian-Mongolian Complex Biological Expedition of the Russian Academy of Sciences and Mongolian Academy of Sciences. It is meant to be used by a wide variety of people, including researchers who study the nature of Mongolia, Inner Asia, and Southern Siberia, geographers working in different areas, botanists, zoologists, soil scientists, ecologists, economists, and specialists of nature protection.

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