Analysis of the dynamics of agricultural lands of the Republic of Tyva using satellite images

Anna Sambuu[1*], and *Leonid* Golubyatnikov[2]

[1]State Budget Scientific Institution of the Republic of Tyva Center for Biosphere Research, 14, Ulug-Khemskaya St., Kyzyl, Republic of Tyva, 667000, Russia
[2]A.M. Obukhov Institute of Atmospheric Physics, RAS, 3, Pyzhevsky lane, Moscow, 119017, Russia

Abstract. The analysis of the dynamics of agricultural lands of the Republic of Tyva (Russia) is carried out. Satellite images from the Landsat-8 spacecraft for the summer period 1987–2021 were used to analyze the spatial distribution of ecosystems on the territory of intermountain basins. Digital land use maps reflect the current situation and contain information about arable land, deposits of different ages, pastures. To determine the age of the deposit, field materials were used, which made it possible to identify the composition of vegetation, varying depending on the age of the deposit, which was reflected in the images. For the first time in the post-Soviet period, a comprehensive analysis of data obtained on the basis of reconnaissance and field work, land use maps using digital technologies was carried out, which allowed us to reveal the current use of more than 30% of arable land, deposits of different ages make up 17–37% of steppe territories, most of the agricultural land is pastures. The interpretation of satellite images made it possible to draw up a map-scheme of the distribution of ecosystems on the territory of the basins. Steppe vegetation is restored on abandoned arable lands. In many fallow areas, bushes of *Caragana bungei* Ledeb. grow. The processes of desertification and salinization are observed in the territory under consideration.

1 Introduction

The steppes of Central Asia, to which the steppes of Tuva belong, are extremely sen-sitive to climatic conditions and anthropogenic impact [1-2]. Over the past century, in the arid regions of Central Asia, the average annual air temperature has increased by 1.0–2.3°C, while the global air temperature has increased by about 0.85°C [1, 3]. The social and economic changes of the last thirty years in Russia, Mongolia and China have led to a significant transformation of agricultural land use in these states and, in particular, pasture farming. The observed climate aridization and increased pasture load cause significant changes in the functioning of steppe ecosystems in Central Asia, which affects the circulation of biogenic elements in this region (reduction of biomass and primary biological products, loss of carbon from soil and vegetation, increased carbon dioxide emissions into

* Corresponding author: sambuu@mail.ru

the atmosphere) [1]. The purpose of this study is to analyze the spatial distribution of plant communities of agricultural lands on the territory of the Central Tuva and Turano-Uyuk basins of the Republic of Tyva according to the data of decoding satellite images. The territory of the Republic of Tyva as a whole is mountainous, with various mountain soils peculiar to them, which occupy 14011 thousand hectares, or 82.2% of the total land area, ravine (hollow) territories – 3039 thousand hectares or 17.8%. The Central Tuva and Turano-Uyuk intermountain basins are located in the central part of the republic approximately between 50°57'–52°02' s.w. and 90°04'–95°51' v.d. The Central Tuva basin is an extensive intermountain depression on the territory of Tyva. The length of the basin from west to east is about 400 km, from north to south – from 25–30 to 60–80 km. The absolute elevation of the relief varies from 600 to 900 m. From the north, the basin is bounded by the ridges of the Western Sayan, from the south – the Western and Eastern Tannu-Ola ridges and the Khorumnug-Taiga ridge, from the west - the Shapshalsky and Tsagan–Shibetu ridges, from the east - the mountain ranges of the East Tuva Highlands. The Central Tuva basin is divided by the low ridge of the Adar Dash into the western and eastern parts – the Khemchik and Ulug-Khem basins, respectively. The relief of the basin is hilly-flat and shallow [4-5]. In places, spurs of neighboring ridges jut into the basin. The valley of the Upper Yenisei cuts through the basin, part of this valley (about 75 km) is flooded by the waters of the Sayano-Shushensky reservoir. The region under consideration is characterized by a sharply continental climate. The average annual air temperature is -4.5 °C, the amount of annual precipitation varies in the range of 220–350 mm, the growing season lasts from May to September. The aridity of the climate increases from east to west. Summer is usually hot: the average temperature in July is +19°C with maximum temperatures in the range of 40–45°C. During the warm period of the year, the greatest amount of precipitation falls (up to 65–85% of the annual amount). In winter, the basin is located in the zone of an extensive and stable Central Asian anticyclone, the center of which is located over Mongolia. Winter in the region is cold with a predominance of clear and sunny days, with little snow (the height of the snow cover does not exceed 20 cm). The average temperature in January is -34°C, minimum temperatures were recorded in the range from -44°C to -49°C [4-5]. On the flat territory of the Tuva basins, ecosystems create a complex mosaic structure of real, dry and desolate steppes [4, 6]. A significant part of these steppe territories of the basin is used as pastures and hayfields, rather small areas are plowed for the cultivation of grain crops.

2 Materials and methods

The analysis of changes in the spatial distribution of ecosystems of agricultural lands in the Central Tuva and Turano-Uyuk basins was carried out on the basis of satellite images from Landsat-5 and Landsat-8 satellites for the summer periods from 1987 to 2021. The source materials of the satellite survey were obtained from the website of the US Geological Survey (http:// earthexplorer.usgs.gov). The data used has a processing level that includes radiometric correction, binding by orbital parameters, and conversion to a standard cartographic projection (UTM) on the WGS-84 ellipsoid. Satellite images were processed in the GRASS geoinformation system using the SMAP classification method.

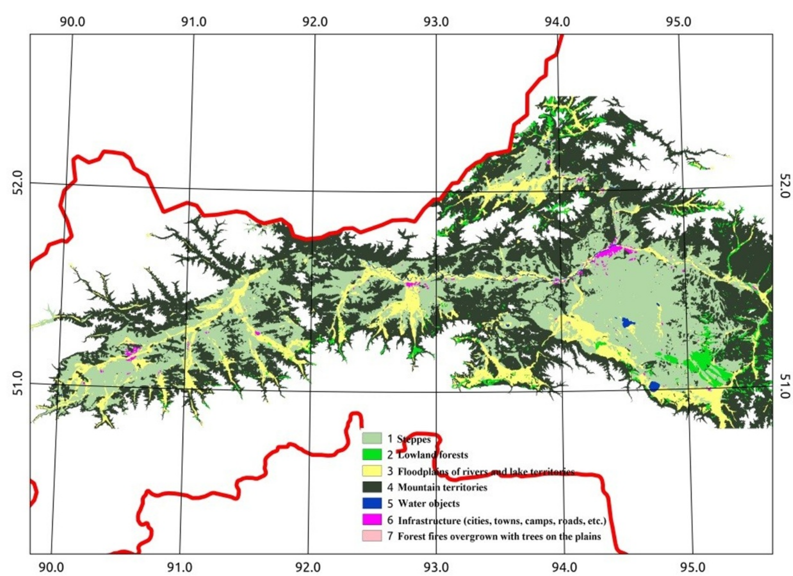
The method of interpretation of satellite images was classification of the spectral image in the Erdas Im-agine software environment with subsequent vectorization in ArcGIS. In satellite images, the basins are recognized as an individual whole by the regular composition of structural elements and are identified as separate geomorphological units. Within the boundaries of individual basins, a quantitative assessment of typological diversity was carried out taking into account objectively reflected in satellite images of local-specific natural and anthropogenic factors of ecosystem differentiation. The natural factors that form the diversity of vegetation cover and are clearly recognized when deciphered include foothill plumes, bottoms of intermountain basins, river valleys, meso- and microrelief forms. The main types of economic activity are plowing, pasture use and deposits.

3 Results and Discussion

To analyze the changes in the spatial distribution of vegetation cover of the Central Tuva Basin and the Turano-Uyuk Basin for the period from the mid-1980s to the present time, the decryption of available images of these territories from Landsat-5, 8 satellites for the summer periods 1987-1994, 1999-2001, 2009-2011 and 2018-2021 was made (hereinafter the designations 1990, 2000 are used, 2010, 2019). The results of processing satellite images for these periods with selected classes of ground surface for the Central Tuva and Turano-Uyuk basins are presented in Figures 1-4.

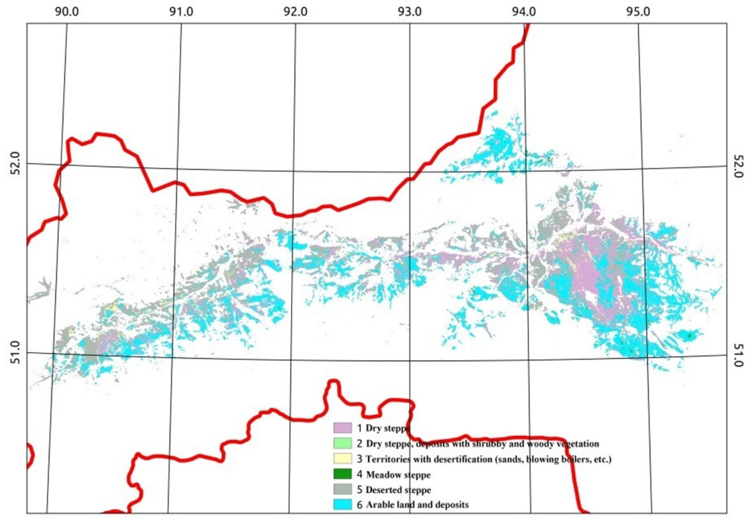
Figures 1a–4a show for the specified time periods spatial distributions on the territory of the basins under consideration of such classes of ground surface as

- Steppe territories.
- Flat forests.
- Floodplains of rivers and lake territories.
- Mountainous territories.
- Water bodies.
- Infrastructure (cities, towns, camps, roads, etc.).
- Forest fires overgrown with trees on the plains.

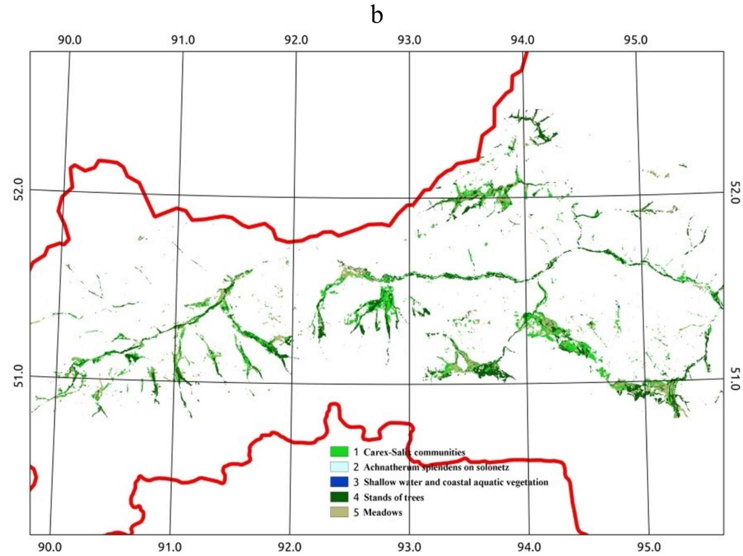


a

 https://doi.org/10.1051/e3sconf/202453901021



b



c

Fig. 1. Maps of the spatial distribution of the main classes of the land surface (a), ecosystems of steppe territories (b), ecosystems of floodplains and lake territories (c) for 1990 The description of the notation is given in the text.

The total area of the territory under consideration is 34.4 thousand km^2, about 47% of which belongs to flat areas. The flat parts of the Central Tuva and Turano-Uyuk basins occupy 15.1 thousand km^2 and 1.1 thousand km^2, respectively. From the late 1980s to the early 2020s, the territories occupied by infrastructure increased by 21%. Figures 1a–4a show the dynamics of the development of such cities as Kyzyl (the northeastern part of the Central Tuva Basin), Shagonar (the central part of the Central Tuva Basin), Chadan, Kyzyl-Mazhalyk (the western part of the Central Tuva Basin), Turan (the Turano-Uyuk basin). During the time period under review, the area of lowland forests decreased by 74% as a result of mainly fires. In the south-east of the Central Tuva Basin in the early 1990s, a large area was occupied by pine forest (Figure 1a). As a result of the fire, most of this forest area was destroyed. Despite the restoration of pine planting and the natural overgrowth of birch and aspen parts of the burning, at present this forest area occupies a much smaller territory (Figure 4a).

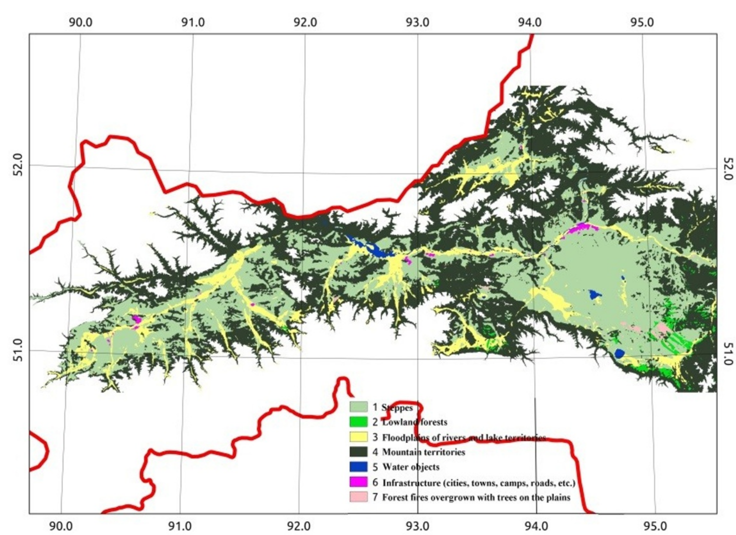
The flat territories occupied by the classes of the land surface "steppes" and "floodplains of rivers and lake territories" were analyzed in more detail.

The following subclasses were identified in the territories occupied by the "steppe" ground surface class:

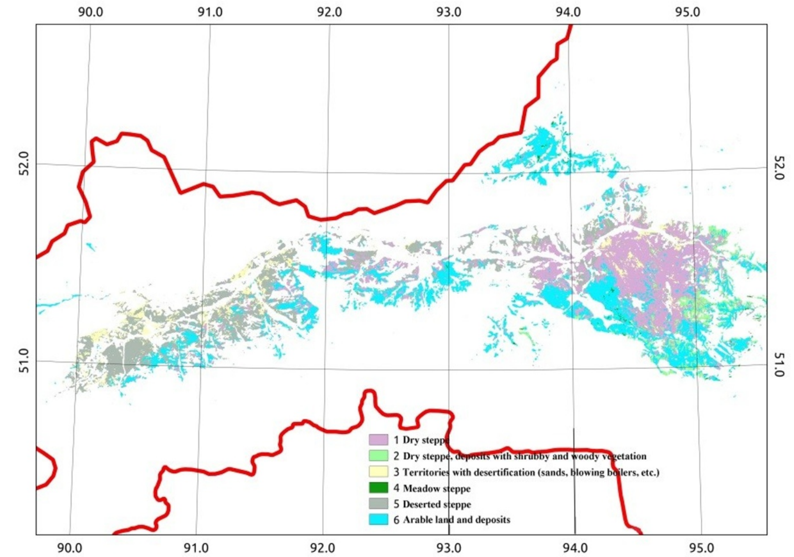
- Dry steppe.
- Dry steppe. deposits with shrubby and woody vegetation.
- Territories with desertification (sands, blowing boilers, etc.).
- Meadow steppe.
- Desolate steppe.
- Arable land and deposits.

3.1 Arable lands

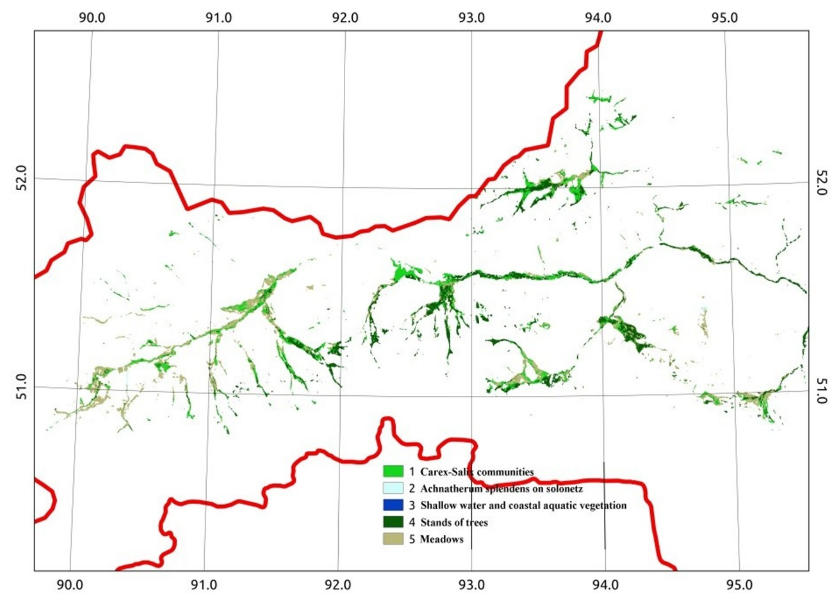
The territories occupied by these subclasses for 1990, 2000, 2010, 2019 are shown in Figures 1b–4b. According to the analysis of satellite images of the studied territory, steppe ecosystems occupy about 10.4 thousand km^2 in the Central Tuva basin, 0.8 thousand km^2 in the Turano-Uyuk basin. In the 1980s, a significant part of the steppe territories was plowed for the cultivation of cereals and melons. According to the data obtained at the end of the 1980s, 37% of the steppe territory was under arable land in the Central Tuva basin, about 76% in the Turano-Uyuk basin. In the Central Tuva basin, mainly steppe territories of its southern and eastern parts were plowed (Figure 1b). In the Turano-Uyuk basin, almost all steppe territories convenient for plowing were occupied by arable land. In the second half of the 1990s, the area of arable land was reduced, many arable lands were transferred to the category of fallow lands. Over time, steppe plant communities are being restored on the deposits. Depending on the degree of restoration of the vegetation cover of fallow lands, the difference between deposits and steppes decreases on satellite images. The reduction of arable and fallow lands in the 2000s and 2010s compared to the 1990s can be seen in Figures 1b, 2b and 3b.



a

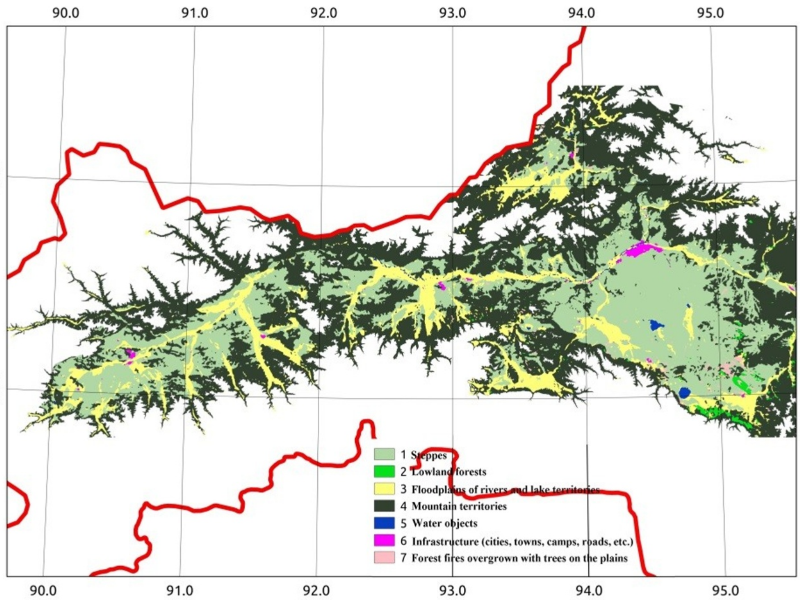


b

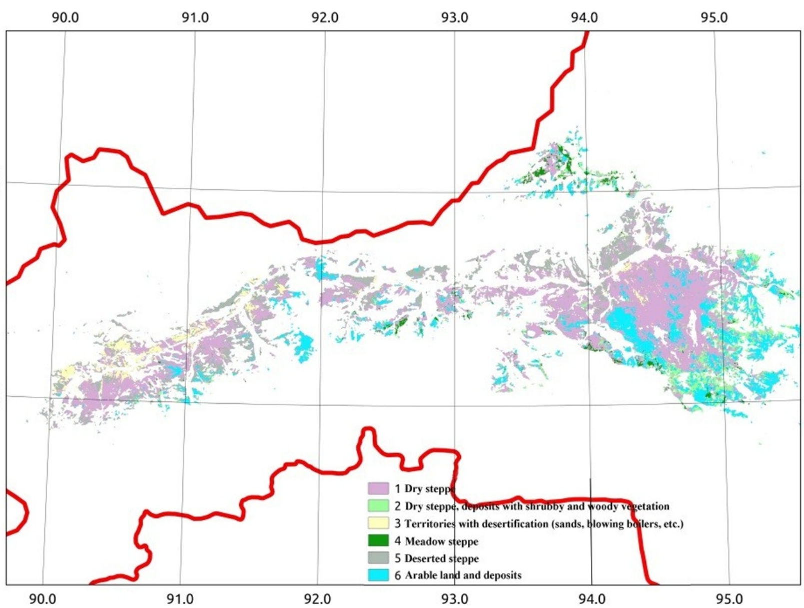


c

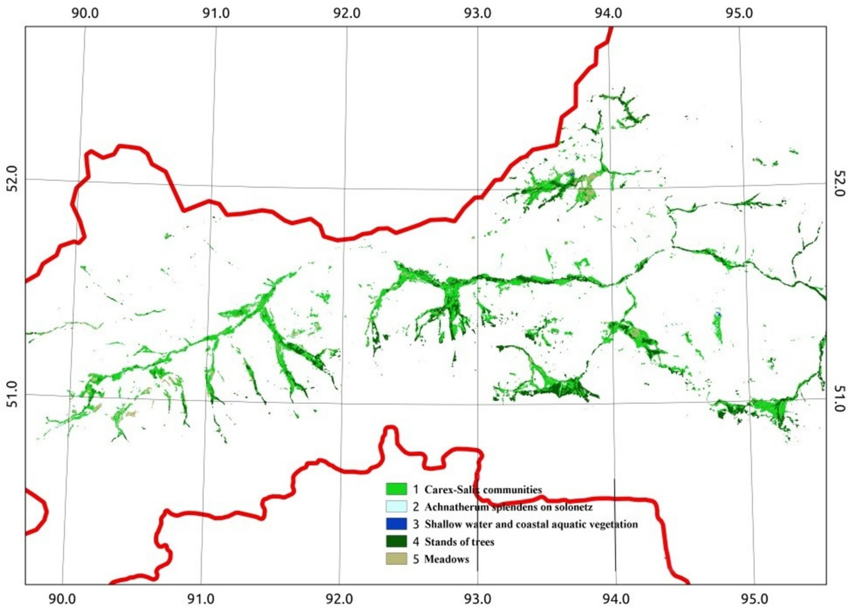
Fig. 2. Maps of the spatial distribution of the main classes of the land surface (a), ecosystems of steppe territories (b), ecosystems of floodplains and lake territories (c) for 2000 The description of the notation is given in the text.


90.0
91.0
92.0
93.0
94.0
95.0
52.0
51.0
1 Steppes
2 Lowland forests
3 Floodplains of rivers and lake territories
4 Mountain territories
5 Water objects
6 Infrastructure (cities, towns, camps, roads, etc.)
7 Forest fires overgrown with trees on the plains

a


90.0
91.0
92.0
93.0
94.0
95.0
52.0
51.0
1 Dry steppe
2 Dry steppe, deposits with shrubby and woody vegetation
3 Territories with desertification (sands, blowing boilers, etc.)
4 Meadow steppe
5 Deserted steppe
6 Arable land and deposits

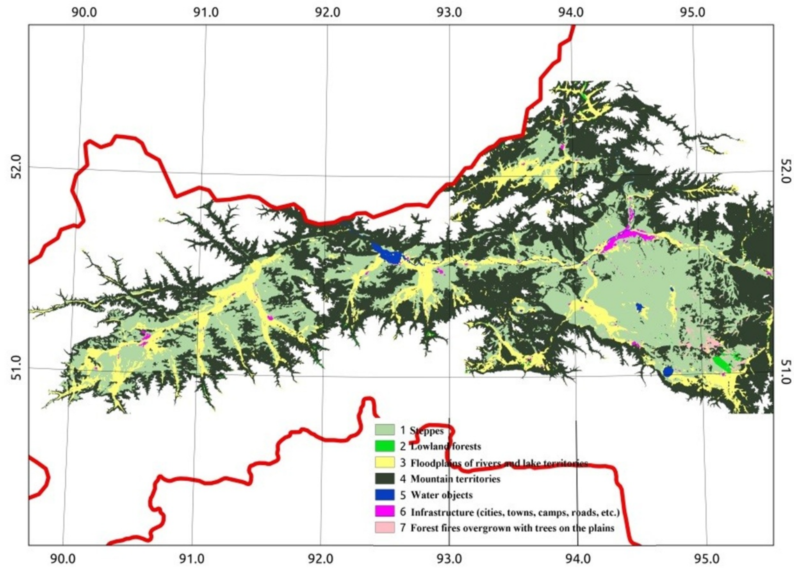
b



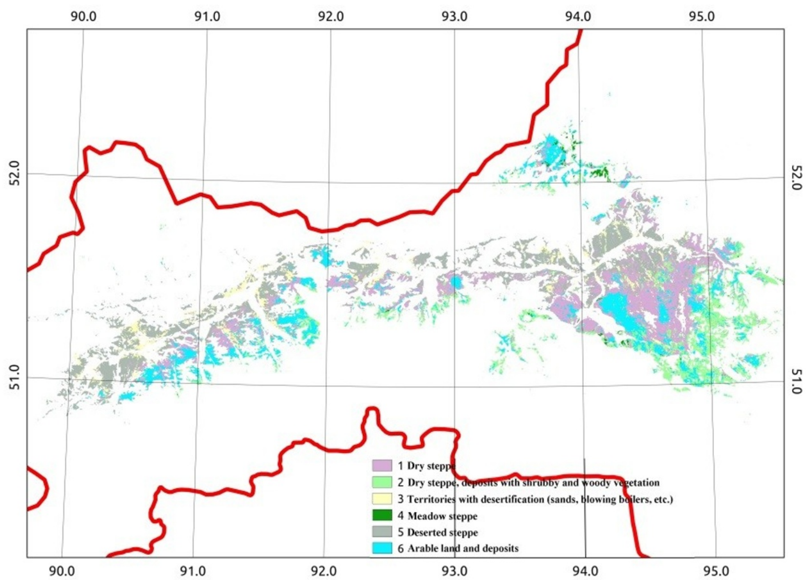
c

Fig. 3. Maps of the spatial distribution of the main classes of the land surface (a), ecosystems of steppe territories (b), ecosystems of floodplains and lake territories (c) for 2010 The description of the notation is given in the text.

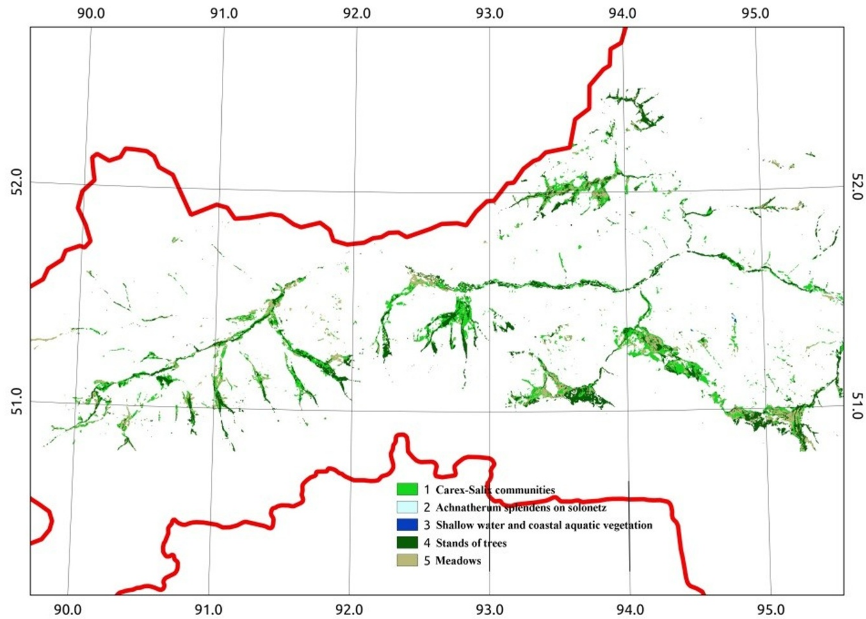
As can be seen in these figures, a significant reduction in arable land occurred in the western and eastern parts of the Central Tuva Basin, the area of arable land also decreased in the Turano-Uyuk basin. In modern satellite images, some deposits of the 1980s do not differ from the steppes. However, the modern plant species composition and surface structure of a number of deposits differs from the surrounding steppe plant communities and the areas occupied by these deposits, as well as the areas of arable fields, are well identified on satellite images. According to satellite images, by 2010, 17% of the steppe territory was under arable land and identified deposits in the Central Tuva Basin, and 21% in the Turano-Uyuk basin. In the 2020s, arable lands and identified deposits in the Central Tuva and Turano-Uyuk basins accounted for about 17% and 37% of the steppe territories of these basins, respectively. A comparison of satellite imagery data for the 2010s and early 2020s (Figures 3b and 4b) shows that over these years there has been an increase in arable land in the Turano-Uyuk basin and the southwestern part of the Central Tuva Basin.


90.0
91.0
92.0
93.0
94.0
95.0
52.0
51.0
1 Steppes
2 Lowland forests
3 Floodplains of rivers and lake territories
4 Mountain territories
5 Water objects
6 Infrastructure (cities, towns, camps, roads, etc.)
7 Forest fires overgrown with trees on the plains

a


90.0
91.0
92.0
93.0
94.0
95.0
52.0
51.0
1 Dry steppe
2 Dry steppe, deposits with shrubby and woody vegetation
3 Territories with desertification (sands, blowing boilers, etc.)
4 Meadow steppe
5 Deserted steppe
6 Arable land and deposits

b



c

Fig. 4. Maps of the spatial distribution of the main classes of the land surface (a), ecosystems of steppe territories (b), ecosystems of floodplains and lake territories (c) for 2019. The description of the notation is given in the text.

3.2 Pastures

At the end of the 1980s, about 60% of the steppe territory of the Central Tuva Basin was used as pastures (23% of this territory is identified as dry steppes, 37% – desolate steppes), mainly these were the territories of the northern part of the basin (Figure 1b). In the Turano-Uyuk basin, 24% of the steppe territory was located outside of arable land at that time, mainly it was foothill territories (Figure 1b). At the present stage, more than 76% and 62% of the steppe territory of the Central Tuva and Turano-Uyuk basins, respectively, are determined from satellite images as territories that do not belong to fallow lands and arable land (Figure 4b for the location of these territories). It should be noted that in the Central Tuva Basin, the area of desolate territories is increasing: in the late 1980s, these territories accounted for 2% of the steppe areas, and in the early 2020s, about 7% of the territory under consideration was covered by the desertification process. From Figure 4b it follows that the mostly deserted territories are located in the western and northeastern parts of the Central Tuva Basin. On the fallow lands of the studied basins, there is an intensive growth of shrubs (mainly *Caragana bungei* bushes) and redines of trees (mainly elms). In the late 1980s, this process of overgrowth was not observed, and in the early 2020s, this process was detected on 17% of the steppe territory of the Central Tuva Basin. Basically, the territories where the growth of *Caragana bungei* and sparse *Ulmus pumila* L. occurs are located in the eastern part of the Central Tuva basin (Figure 4b).

The following subclasses were allocated in the territories occupied by the land surface class "floodplains and lake territories":

- Sedge-willow communities.
- Achnatherum splendens (Trin.) Nevski on salt flats.
- Shallow water and coastal vegetation.

- Stands of trees.
- Meadows.

The territories occupied by these subclasses for 1990, 2000, 2010, 2019 are shown in Figure 1b–4b. According to the analysis of satellite images, these ecosystems occupy about 4.2 thousand km^2 of the studied territory. In the floodplains of rivers and lake territories, under the influence of natural and anthropogenic-caused successional processes, during the time period under consideration, there was a change in the areas occupied by these ecosystems. Analysis of satellite images showed that in the period from the late 1980s (Figure 1b) to the early 2020s (Figure 4b) in the floodplains of rivers and lake territories of the basins under consideration, stands have practically not changed the occupied area of growth. Meadow communities have expanded the area of growth by 1.5 times. There is a decrease (by 1.7 times) in the area of growth of sedge-willow communities. During the period under review, the area of chia growth has increased significantly (more than 10 times). It should be noted that the modern territory occupied by the *Achnatherum splendens* is small and is about 70 km^2. However, the expansion of the territories under the crops during the period under review indicates an increase in the salinization process in these territories.

4 Conclusion

The results of processing satellite images from 1987-2021 with selected classes of ground surface for the intermountain basins of the Republic of Tyva showed that the total area of the intermountain basins is about 18.6 thousand km^2. Currently, the plowing of land in the territory of the basins is minimal (less than 10% of the territory). Steppe vegetation is gradually being restored on abandoned arable lands (deposits). At the moment, the plant species composition and surface structure of a number of deposits differs from the surrounding steppe plant communities and the areas occupied by these deposits are well identified on satellite images. It should be noted that the process of restoring vegetation cover on deposits older than 20 years leads to the appearance of plant communities that are close to the indigenous steppe communities in species composition. In many fallow areas, bushes of *Caragana bungei* grow. As follows from the compiled map-scheme, in the eastern part of the basins, grass-wormwood and wormwood-grass dry steppes predominate. The central part of the basins is a complex mosaic of steppe ecosystems of different types. In the eastern part of the basin, large areas are occupied by sagebrush-cereal dry steppes. Significant areas on the territory of the Central Tuva Basin are used as pastures. With intensive pasture load, which is observed on the pasture lands of this basin, in steppe ecosystems there is a violation of the structure of the grass stand and a change in the species composition of communities. A significant pasture load contributes to the development of desertification processes of the territory, and there is also an increase in the salinization process.

Acknowledgement

The research was carried out as part of the most important innovative project of national importance “De-velopment of a system for ground-based and remote monitoring of carbon pools and greenhouse gas fluxes in the territory of the Russian Federation, ensuring the creation of recording data systems on the fluxes of climate-active substances and the carbon budget in forests and other terrestrial ecological systems” (Regis-tration number: 1022090600007-9).

References

1. I.M. Gadzhiev, A.Yu. Korolyuk, A.A. Titlyanova, Steppes of Central Asia.: Siberian Branch Russ. Acad. Sci., Novosibirsk (2002)
2. A.N. Zolotokrylin, Climatic desertification. Science, Moscow (2002)
3. M. Collins, R. Knutti, J. Arblaster, Long-term Climate Change: projections, commitments and irreversibility. Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, USA, 1029–1136 (2013)
4. A.A. Titlyanova, A.D. Sambuu, Succession in grass ecosystems, Siberian Branch Russ. Acad. Sci., Novosibirsk (2016)
5. M.F. Andreychik, Air temperature extremum dynamics – factor of climate warming in Central-Tuva hollow of the Tuva Republic, Bulletin of the Krasnoyarsk State Agrarian University, **5**, 124-128 (2014)
6. A.D. Sambuu, T.N. Prudnikova, L.L. Golubyatnikov, Natural Resources in the Republic of Tyva. (II), Garamond, Novosibirsk (2020)