Changes in the Activity of Higher Vascular Plants Species in the Ob Plateau Landscapes (Altai Krai, Russia) Due to Anthropogenic Transformation

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Abstract

The paper deals with the attempt to assess the changes in plant species activity as a result of anthropogenic transformation of landscapes. The approaches of the Russian–Soviet school of landscape cartography and land cover mapping based on remote sensing data are used. The species activity was determined by standard methods accepted in the Russian–Soviet floristics. Using the specific examples, the main trends of the species activity changes from the natural condition of the territory to the present moment and in the last 40 years are shown.

Keywords

Plant species activity · Landscape mapping · Remote sensing data Land cover classes

Introduction

The Altai Krai flora is currently detected with high completeness, and the native and alien species in its structure are recognized (Silantyeva 2013). However, the attempts to reconstruct the process of flora anthropogenic transformation only at a general qualitative level were made. In other words, it is known which species belong to native flora and what species and about what time have been entered due to human activities. Nevertheless, the quantitative assessment of changes in the activity (Yurtsev 1968) of native and alien species under the action of anthropogenic pressure in the Altai Krai is still not performed.

Of course, the most accurate and correct way to study changes in the activity of specific species in the landscape is the direct floristic surveys in different time slices. It should be noted such surveys require much time and many researchers, so they cannot be carried out simultaneously over

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large areas such as the Altai Krai, or even the Ob plateau. In addition, often the lack of similar data for the past time slices excludes the possibility of comparison. In this case, it is necessary to use indirect methods for determining the species activity that is especially important for the past time slices.

Flora is a component of the landscape and transformed together with other components and the landscape as a whole. We asked ourselves how we could assess the anthropogenic transformation of the flora as a result and part of anthropogenic transformation of landscapes.

This is possible using the identification of linkages between the partial components of the landscape, as well as between the components and physiognomic characteristics of the landscape (e.g., land cover). Specific species are associated with specific ecotopes, so the species distribution in the landscape can be assessed through the distribution of ecotopes. Accordingly, changes in the distribution of species can be estimated due to changes in areas and distribution of relevant ecotypes. The study of changes in the area and distribution of ecotopes is only possible with the use of cartography and a series of maps for two or more time slices. In this work, we attempted to link changes in the structure of landscape and flora.

Methodology and Study Area

In 1995–2016, we carried out floristic (Zolotov 2009) and landscape (Chernykh and Zolotov 2011) research on the Ob plateau within the key model territories (Fig. 1). The result is a data array that allows to compare floristic and

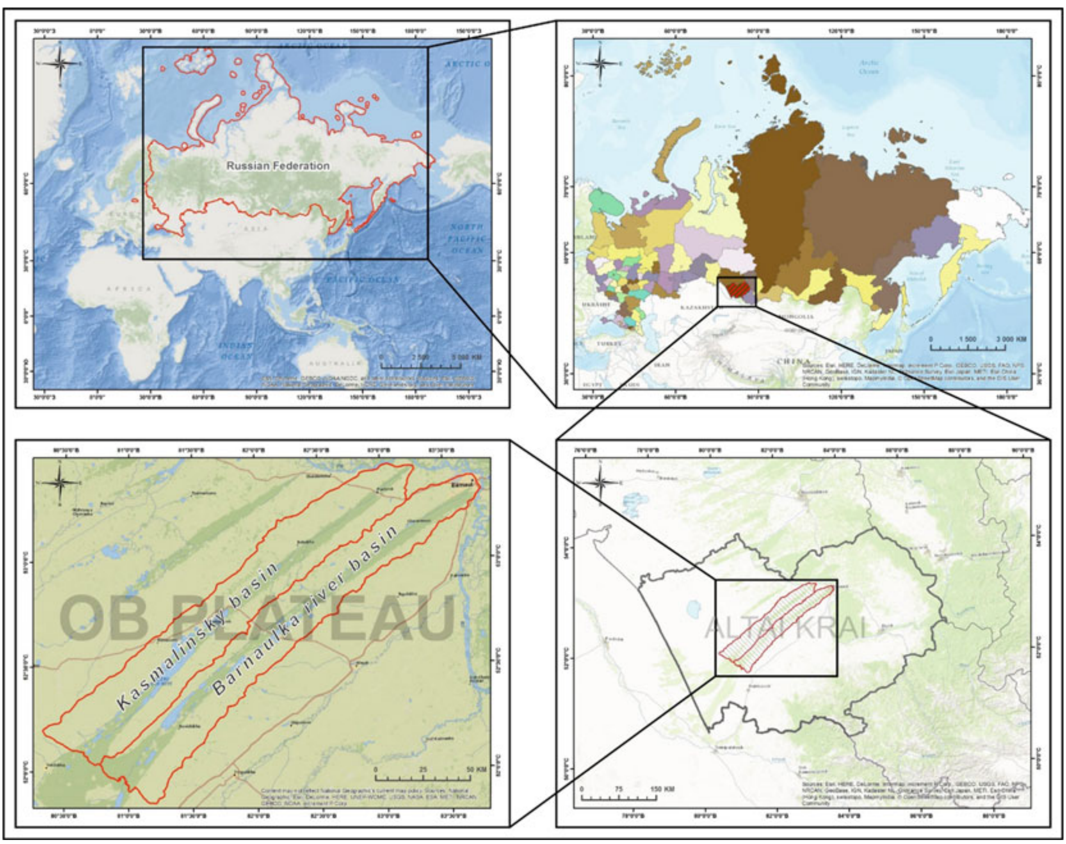


Fig. 1 Study area: the Kasmalinsky and Barnaulka river basin at the Ob plateau

landscape diversity, to explore their interrelation, and to assess the anthropogenic transformation of the flora due to anthropogenic transformation of landscapes. To our opinion, such a goal requires to solve three particular tasks:

(1) Creating a map of the restored landscapes based on the reconstruction according to the available historical (archival) data and documents. The detection of anthropogenic landscape dynamics for the considered periods including the remote sensing data using.
(2) The complete inventory of the modern flora and its analysis, gathering historical data on the occurrence and abundance of species in the past. The division of species into anthropophobic, hemianthropophobic, hemianthropophilous, and anthropophilous ones.
(3) The determination of the nature of relationship between species and ecotopes (eurytopic, hemieurytopic, hemistenotopic, and stenotopic species) for extrapolation and interpolation of data on different periods.
(4) To assess the landscape situation before the major economic development of the beginning of eighteenth century, the map of restored landscapes of the Kasmalinsky and Barnaulka river basins (Fig. 3) is composed. The map is made in the tradition of Soviet–Russian school of landscape science at the level of types of terrain groups (output scale of 1:500,000, working scale of 1:200,000). Previously, we produced a similar map for the Barnaulka river basin (output scale of 1:250,000, working scale of 1:100,000) (Chernykh and Zolotov 2011). Landscape dynamics for the last 40 years is studied using remote sensing data.
(5) To identify the role of higher vascular plant species in the landscape, we used the activity (Yurtsev 1968; Yurtsev and Petrovsky 1994; Zverev 2007)—integral index of occurrence and abundance.

It is obvious that the reconstruction cannot give absolutely accurate data. Therefore, for many rare non-stenotopic species, it is extremely difficult to reliably estimate their activity in the past, especially because they are not mentioned in previous floristic checklists. However, for many widespread, dominant, stenotopic, and flagship species, it is possible to evaluate the activity knowing the landscape situation in the past with sufficiently high precision. This is possible because of ecological and coenotic characteristics of higher vascular plant species in the last hundreds and thousands of years remained practically unchanged.

In general, this study is our first step in the direction of set goal and tasks. Nevertheless, the used approach allowed us to draw some interesting conclusions.

Results and Discussion

Highest hierarchical levels of the Ob plateau landscape differentiation are regional and subregional. The regional level is manifestation of zonal or bioclimatic differentiation: steppe and forest-steppe zones (landscape types), droughty and temperate-droughty steppe, southern forest-steppe subzones (landscape subtypes) (Fig. 2). The subregional level is the three basic landscape genera of the Ob plateau: *zonal* watershed-loessial (loessial ouval plateau), *intrazonal* halohydromorphic (ancient-alluvial flat with flat-bottom depressions), *extrazonal* psammomorphic (eolian-ancient-alluvial bumpy with flat-bottom depressions) (Chernykh and Zolotov 2011).

Anthropogenic transformation of the Ob plateau territory as a result of economic development was determined by the spatial organization of landscapes. Anthropogenic transformation degree increases in the landscape genera row: *extrazonal* psammomorphic → *intrazonal* halohydromorphic → *zonal* watershed-loessial (Fig. 3).

Weakly transformed are extrazonal psammomorphic landscapes (4371 km^2—35%), within which the forestry (felling in strip pineries) and residential activities were primarily evolved. This category also includes the valleys of small rivers and temporary watercourses within the zonal and intrazonal landscapes.

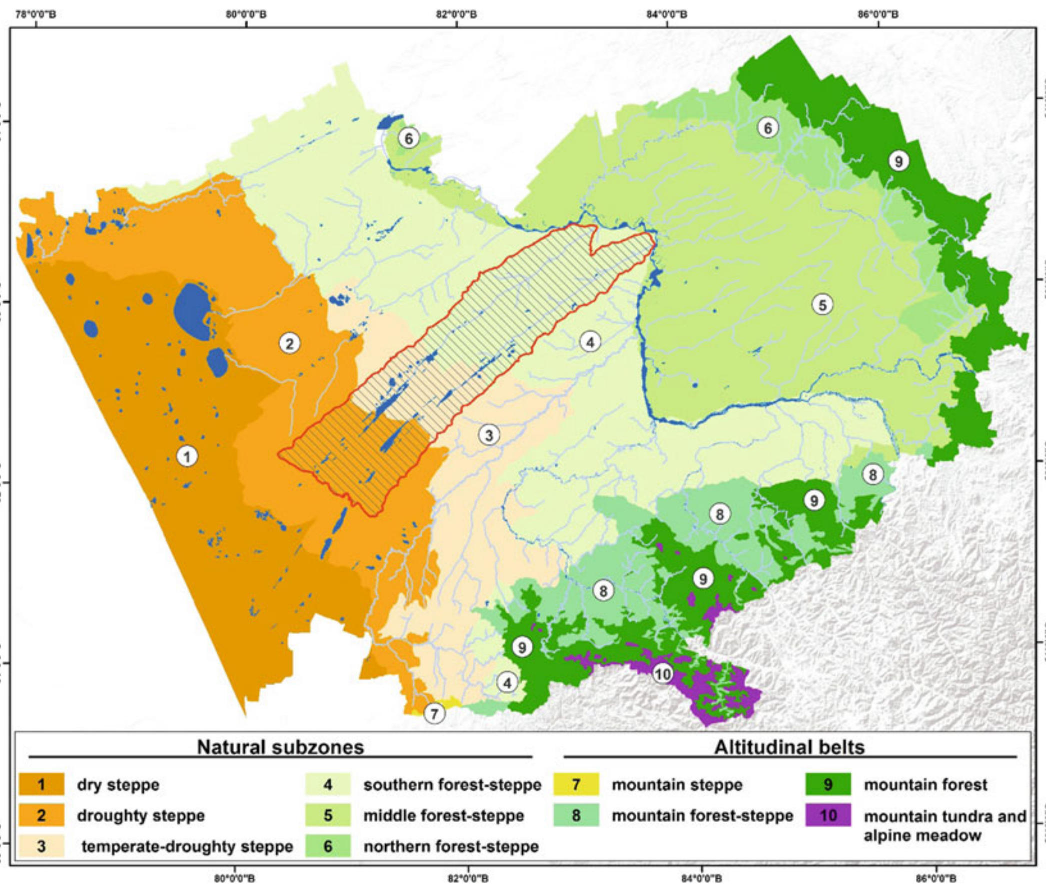


Fig. 2 Natural subzones and altitudinal belts of Altai Krai

Medium transformed are intrazonal halohydromorphic landscapes (1972 km^2—16%). Within their limits, the arable land is limited by light granulometric composition (loamy sand, light loam, and sand) and paleohydromorphism (plenty of flat-bottom depressions and saline areas unsuitable for growing). However, there are concentrated majority of settlements and main pastures.

Much transformed are zonal watershed-loessial landscapes (6155 km^2—49%), which are optimal for agriculture, first of all plowing. Here, all suitable areas are under cultivation, and pastures are confined to the balkas (small flat-bottom valleys), small river valleys, suffusion depressions, and residual lake basins. Settlements are usually small, relatively rare, and gradually disappear from the 1960s.

Some reduction of anthropogenic transformation is observed in landscape subtypes row: droughty steppe → temperate-droughty steppe → southern forest-steppe. This is due to the increase of precipitation, intensification of erosion processes, and consequently area unfit for cultivation. Most clearly, this zonal trend is apparent in the zonal watershed-loessial landscapes. Less clearly, it is observed in intrazonal halohydromorphic landscapes, especially because their area is reduced in the described direction also under the influence of erosion processes. The manifestation of this regularity is almost imperceptible in extrazonal psammomorphic landscapes that are not affected by plowing.

It is well known that the higher vascular plant species change their activity in landscapes as a result of anthropogenic transformation. In this

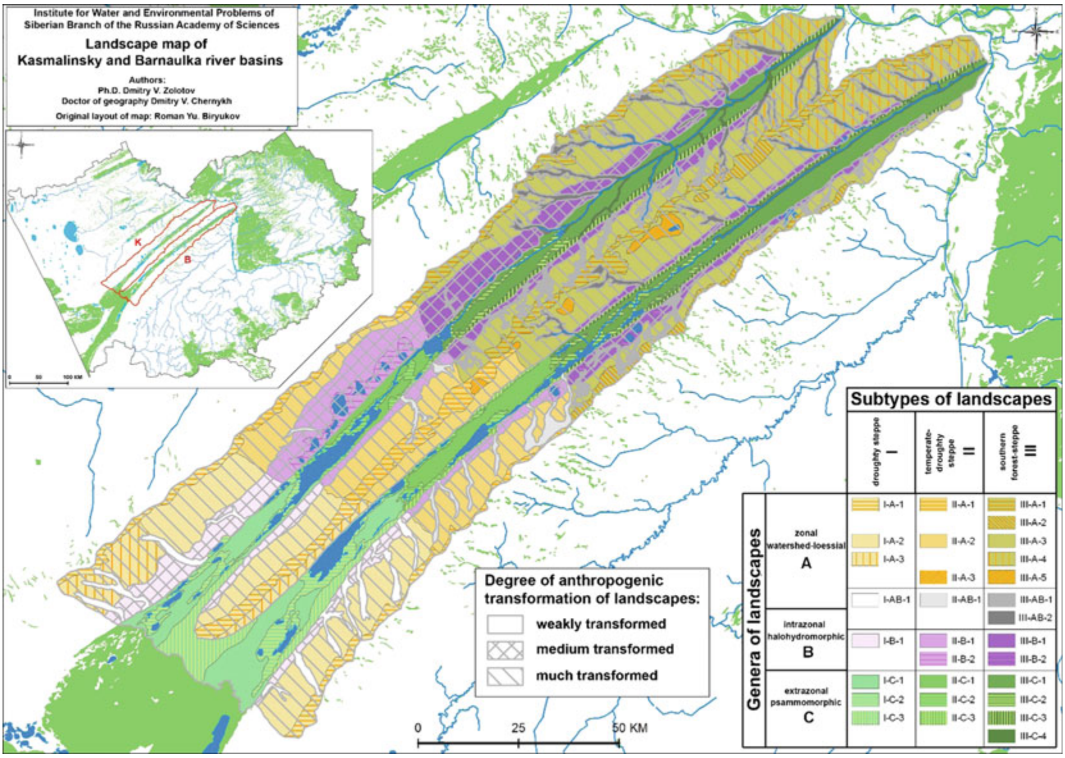


Fig. 3 Landscape map of the Kasmalinsky (K) and Barnaulka (B) river basins with degree of anthropogenic transformation at level of types of terrain groups

case, anthropophobic species reduce their activity, but anthropophilous ones (apophytes and aliens) increase. We used the activity (A) gradation proposed by B.A. Yurtsev (Yurtsev 1968; Yurtsev and Petrovsky 1994; Zverev 2007) for species in landscape: 1—inactive (IA), 2—low-active (I), 3—low-mid-active (intermediate I–II), 4—mid-active (II), 5—high-mid-active (intermediate I–III), 6—high-active (III), 7—particularly active (IIIA).

Theoretically, the amplitude of changes of the species activity due to anthropogenic transformation of landscapes can be from 0 to ±7. We offer the following gradation to estimate activity changes (ΔA): 0—no changes, 1—slight (visible), 2—significant (strong), 3 to 4—very significant (very strong), 5 to 7—extreme (catastrophic).

As a result of anthropogenic transformation of the Ob plateau landscapes from the initial natural state to a modern one, the activity of steppe species, especially dominants (*Stipa zalesskii* Wilensky, *S. pennata* L., *S. capillata* L., *Festuca valesiaca* Gaudin), is very significantly and extremely decreased in zonal and intrazonal landscapes.

The activity of halophytes [*Atriplex verrucifera* M.Bieb., *Camphorosma songorica* Bunge, *Salicornia perennans* Willd., *Suaeda corniculata* (C.A.Mey.) Bunge] in intrazonal landscapes is almost not decreased and in some location increased due to secondary salinization.

Minor changes associated with felling have affected the species of mesophytic strip pineries in extrazonal landscapes. First of all, there are trees: *Pinus sylvestris* L., *Betula pendula* Roth, *Populus tremula* L.

On the contrary, the species of forest swamps (*Oxycoccus palustris* Pers., *Drosera anglica* Huds., *D. rotundifolia* L., and other) and moist forests have visibly reduced their activity due to anthropogenic disturbances of hydrological regime and climate warming. The activity of many alien species (*Acer negundo* L., *Cannabis sativa* L., *Erigeron canadensis* L., *Hordeum jubatum* L., *Pastinaca sylvestris* Mill., *Trifolium fragiferum* L., *Xanthium strumarium* L.) has increased significantly, very significantly, and extremely.

We have estimated the anthropogenic and natural dynamics of landscapes of the Kasmalinsky and Barnaulka river basins in the last 40 years using remote sensing data and geoinformational methods (Fig. 4). Multi-temporal series of satellite imagery were used: 1975–1976 Landsat 2 MSS; 2001 Landsat 7 ETM; 2015 Landsat 8 OLI (http://glovis.usgs.gov). The analysis of spatiotemporal changes of landscapes has fundamental value to the understanding and resolution of many social, economic, and environmental problems (Vinogradov 1981, 1984; Mamay 2008; Rafaela et al. 2009; Fichera et al. 2012).

At the initial stage of working were selected cloudless and slightly cloudy scenes close by shooting date (Fig. 5). The data were processed using the software complex ERDAS 2013. The geometric and radiometric correction, layer stack, and preparation of seamless mosaics including color balancing were made. Further, the region of interest from the complete scenes of images was cut out (Fig. 6).

Automated classification was carried out in two stages. In the first stage a mask of agricultural land was created, because the classification problems associated with the separation of this land cover class from others due to the overlap of spectral signatures. Agriculture mask was created by calculating the normalized difference vegetation index (NDVI) (Fig. 7) and the selection of values for open soil (shooting date was specially chosen for the time when the fields are free from crops). In the second stage, the unsupervised classification of images—algorithm Iterative Self-Organizing Data Analysis Technique (ISODATA) using the obtained agriculture mask was realized. Validation of the classification reliability for water bodies was carried out using the modified normalized difference water index (MNDWI) (Fig. 8) (Xu 2006).

The classification resulted in three land cover maps corresponding to the shooting dates (Fig. 9). Four land cover classes were allotted: W—water body, AS—agriculture and settlement, F—forest, and GSW—grassland, steppe, and wetland. The obtained land cover maps further were analyzed in the software package QGIS Desktop 2.10, Modules for Land Use Change Simulations (MOLUSCE) (http://hub.qgis.org/projects/molusce). According to the analysis results, we compiled the change matrix (Ramachandra et al. 2012; Areendran et al.

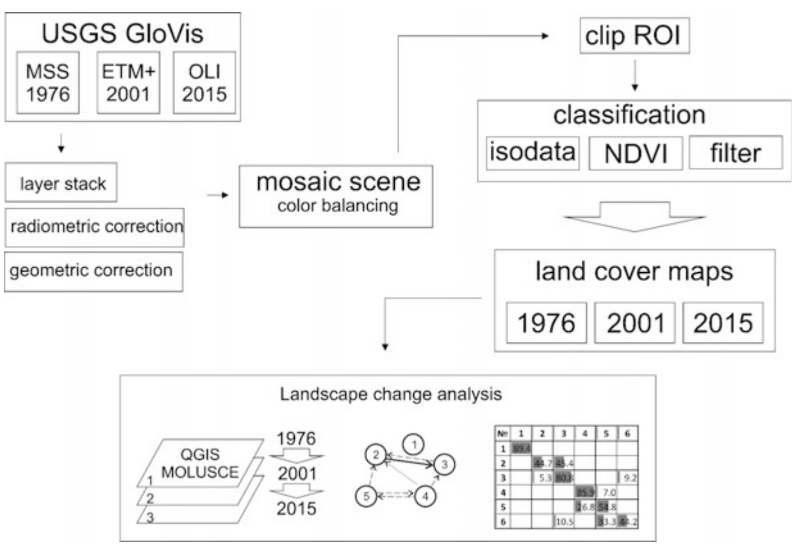
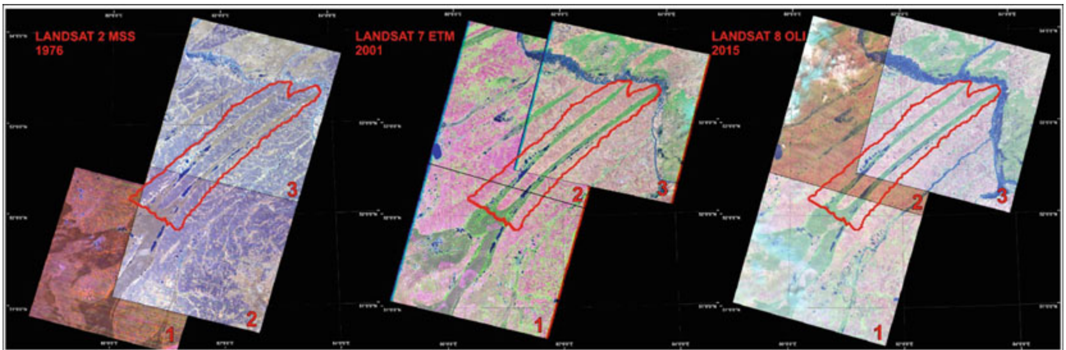


Fig. 4 Flowchart of the remote sensing data analysis



Satellite	Sensor	Scene	Date	Path	Row
Landsat 2	MSS	1	1975.08.14	161	024
		2	1976.05.09	160	024
		3	1976.05.09	160	023
Landsat 7	ETM	1	2001.05.25	149	24
		2	2001.05.25	149	23
		3	2001.05.02	148	23
Landsat 8	OLI	1	2015.05.08	149	24
		2	2015.05.08	149	23
		3	2015.05.01	148	23

Fig. 5 Landsat scenes used in the study

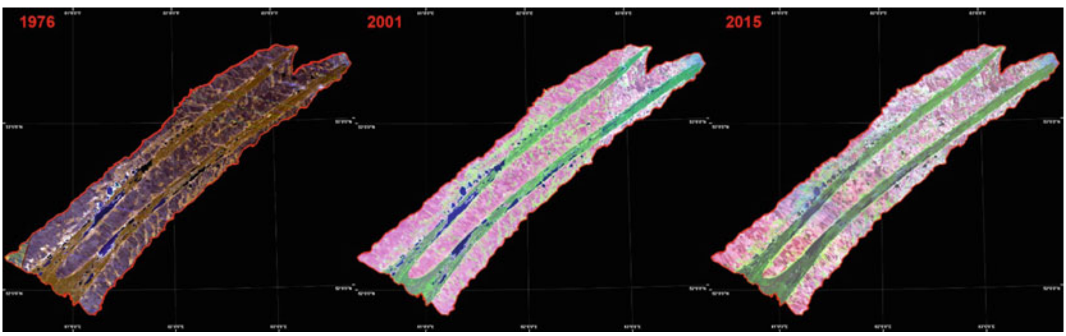


Fig. 6 Region of interest at the Landsat images

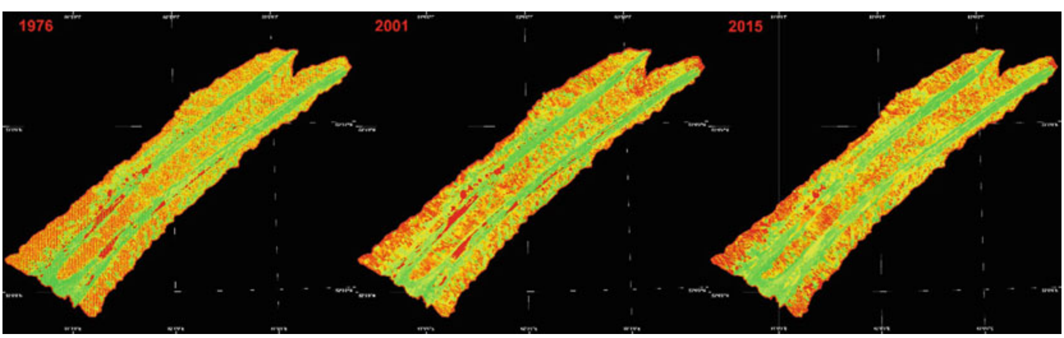


Fig. 7 NDVI maps derived from the Landsat imagery

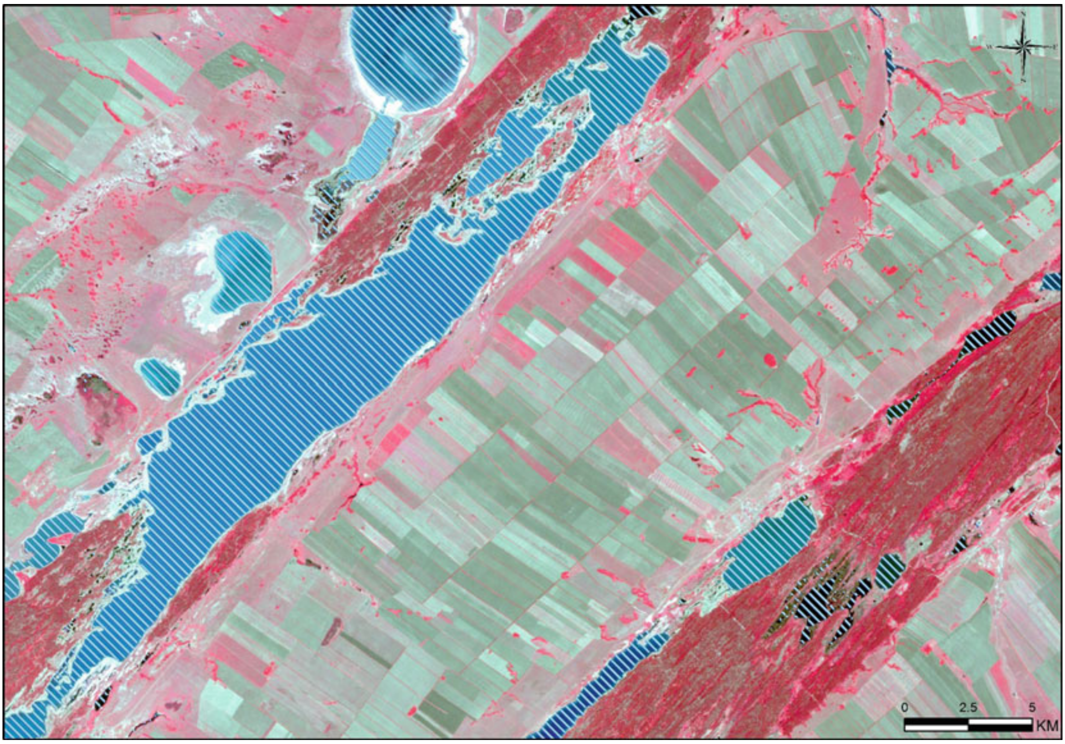


Fig. 8 A fragment of the Landsat image with the overlay of the water body layer obtained using the calculation of MNDWI

2012), which describes the spatial frequency of transitions of different class contours from one to another in the images of different years (Fig. 10).

We are seeing a gradual decline (8%) in the share of AS (mainly arable lands), which primarily transformed into fallows and secondary steppes and to a lesser extent in forests. This process takes place from the time of total plowing (the development of virgin and fallow lands) in 1954–1961 years. The result is a slight (ΔA = +1) increase of steppe graminoids (*Stipa* spp., *Festuca* spp.) activity due to the overgrowth of fallow lands. To a lesser extent, this process has touched herbs (forbs) as a more inert component of steppe plant cover.

Natural herbal (grass) communities (GSW) are the most dynamic class. They largely returned to agricultural use and are covered by forest. The forest generally has slightly changed their area becoming a natural herbal communities and agricultural lands. Such direct and inverse transitions because of the absence of one direction do not allow assessing the changes of geographical activity of the species peculiar to these ecotopes.

Significant changes occur in water body area. They consistently increase the share of its area from 3.08% in 1976 to 5.40% in 2015. However, these changes are not directed because the analyzed images belong to the period of spring floods. This is a reaction to the change in the hydrothermal conditions of a particular time period. Increasing the area of water surface occurs mainly due to the temporary water bodies and overflow of lakes and rivers most often located in extrazonal and intrazonal landscapes (Fig. 11).

The filling of these temporary water bodies depends on the hydrothermal conditions in August–September of the previous hydrological year, the cold period (November–March), and snowmelt period (April–May) of the current hydrological year (Fig. 12). The most important

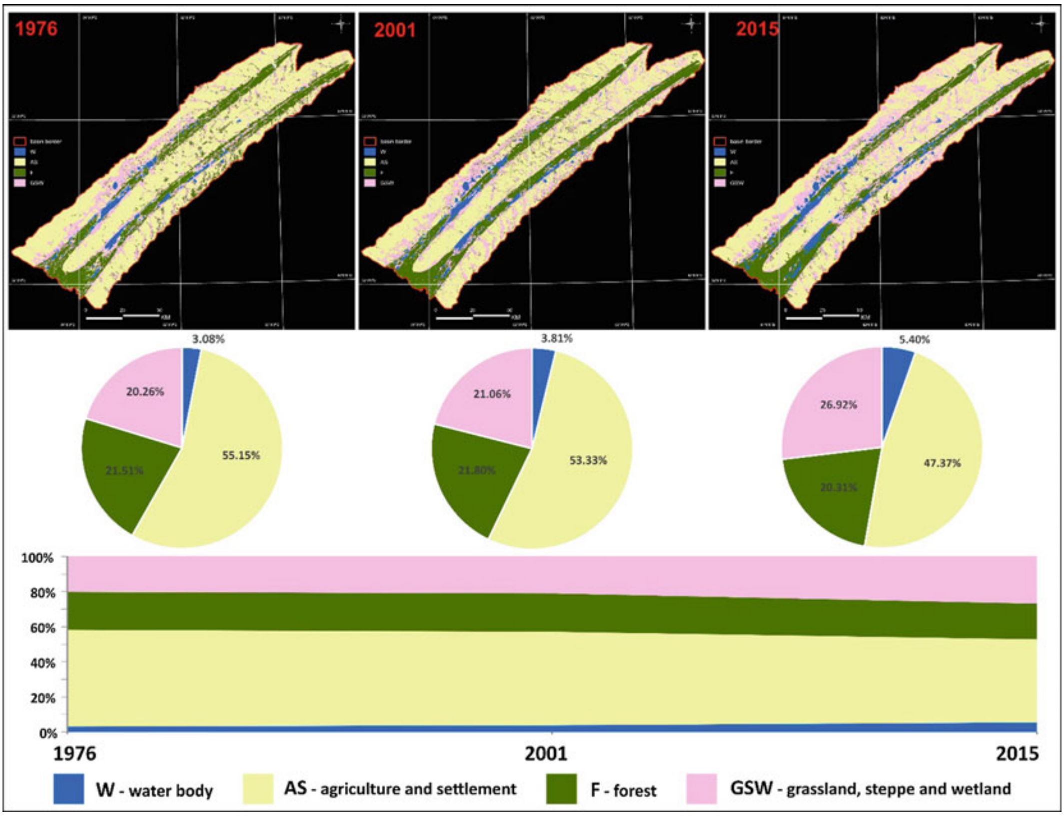
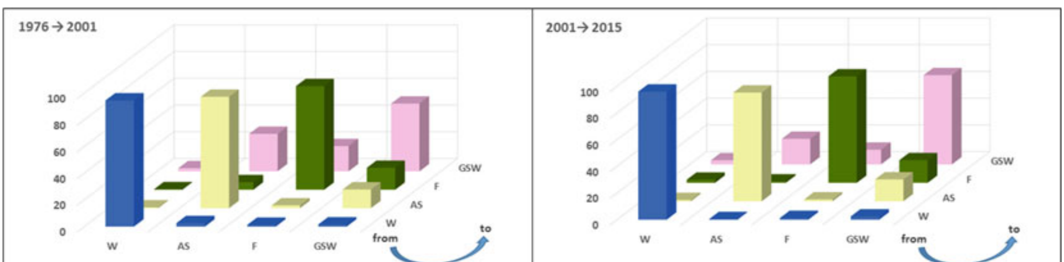


Fig. 9 Area statistics and allocation of land cover changes (%)



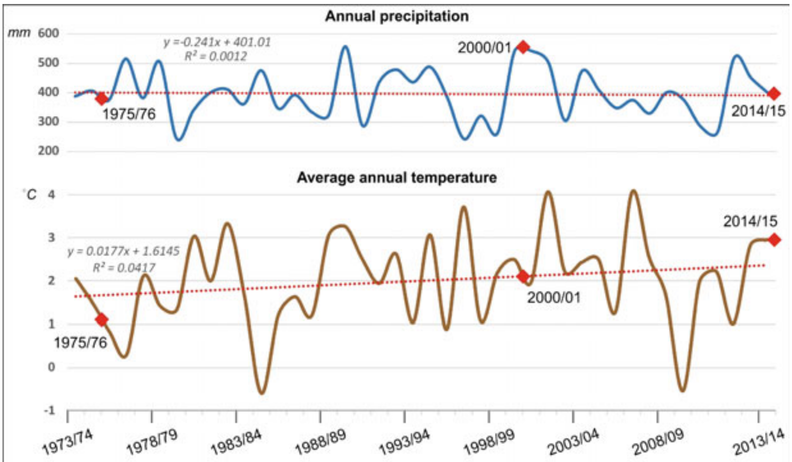
1976 → 2001	W	AS	F	GSW
GSW	2.30	28.09	18.89	50.72
F	0.38	5.66	77.56	16.40
AS	0.55	83.42	2.07	13.95
W	94.46	2.60	1.32	1.62

2001 → 2015	W	AS	F	GSW
GSW	3.11	19.12	10.95	66.82
F	2.29	1.04	79.73	16.93
AS	0.91	81.42	1.37	16.31
W	95.93	0.41	1.25	2.41

Fig. 10 Land cover changes matrix (%) between 1976 and 2001, 2001 and 2015. It shows the change matrix of different land cover classes during periods 1976–2001 and 2001–2015 years. In general, all the land cover classes are relatively stable over time

is the situation before and after a cold period because at this time there is formation of conditions for transformation of winter precipitation into surface and ground water runoff. In 1975, the relatively dry autumn contributed to the fact that soils were poorly saturated with moisture. Cool April (average temperature +2.9 °C) ensured a smooth process of snow melting. The result was a significant decrease of the moisture received by surface water bodies.

Fig. 11 Changes of water body area



		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Nov-Mar	Apr	May
1975/76	pr., mm	30.4	36.5	29.7	39.1	19.1	14.6	42.8	17.3	132.9	13.4	9.9
	t_{avg}, °C	15.8	11.1	2.5	-9.0	-16.7	-13.5	-18.1	-10.9	-13.6	2.9	12.2
2000/01	pr., mm	91.2	25.0	48.4	41.3	54.7	38.4	23.1	21.4	178.9	41.3	42.0
	t_{avg}, °C	18.1	10.9	-0.4	-11.7	-12.3	-19.2	-14.8	-3.9	-12.4	3.0	15.9
2014/15	pr., mm	45.0	58.0	54.0	41.7	17.5	23.9	11.8	21.3	116.2	31.9	40.6
	t_{avg}, °C	17.8	8.1	1.4	-8.4	-12.9	-13.1	-12.9	-6.1	-10.7	5.3	13.1

Fig. 12 Meteorological conditions of the considered years using the Rebrikha (southern forest-steppe) station within the study area

Hydrothermal conditions of 2000/01 and 2014/15 were very similar. However, the key distinction is the difference in the intensity of snowmelt, which is largely determined by the April temperatures. April 2015 was more than 2 °C warmer, which contributed to intensive melting of snow cover and rapid increase of water level in reservoirs.

These fluctuations of the water bodies area have no noticeable effect on geographical and landscape activity of species because these periodically flooded areas are adapted to flooding (wetlands). In other words, there are no radical ecotopological changes of the landscape structure during such a seasonal variations. The changes in the activity of plant species of exposed to flooding ecotopes can be recorded in a detailed comparison of specific ecotopes during the stationary and semi-stationary research.

Conclusions

1. Plant species activities are closely linked to the anthropogenic impact on the natural landscapes. Activity changes are different for

various groups (ecological, coenotic, and other) and species.

2. During the period of economic development of the territory, most of native steppe species have very significantly and extremely reduced their activity. It is also true for the species of forest swamps and moist forests. Slight activity changes are peculiar to other groups. The activity of alien species is mostly increased.
3. In the last 40 years, we can observe a slight increase in the activity of steppe graminoids due to the formation of fallow lands and secondary steppes from arable lands, but it hardly touches another herbs (forbs).
4. Seasonal and annual fluctuations in area of water bodies and mutual reciprocating transitions of the main land cover classes have no noticeable effect on the geographical activity of the species in the study area.

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