On the experience of field monitoring and remote sensing technologies integration in regional phytodiversity conservation

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Abstract. The Samara regionpossesses the powerful industrial complex, up to 80% of the territory has been turned into agrocenoses, the third largest in Russia dual-core urban agglomeration of Samara-Tolyatti was developed. The natural complexes are confined to relatively small areas in the space of agricultural land, dissected by roads and saturated with settlements.The traditional terrestrial (field) monitoring of biodiversity is associated with valuablelabour- and time costs. The attraction of remote sensing (RS) allows spatially integrated information for vast territories with time minimization, but it requires a system of regional reference (etalon) polygons for adequate proceeding of RS data. Such a system has been developed since 2016 by specialists in the field of ecology, botany and geoinformatics at Samara University.The work implementation in 2016-2022 was carried out in two directions: - formation of a regional system of ground reference plots (etalons) that provide work with RS data; - assessment of the possibilities for the UAVsuse for monitoring of plant communities state, previously carried out exclusively by ground-based methods. The main result of our joint efforts is regionally adjusted classifiers that allow the most efficient processing of available remote sensing materials corresponding to various types of natural and anthropogenically transformed vegetation areas of the Samara region. We also confirmed the point of view on the high efficiency of using UAVs to identify and analyze the state of anthropogenically transformed and natural areas, including small natural objects.Thus, joining the efforts of specialists in various fields and integrating classical and innovative technologies is the most realistic way to study, monitor, and conserve regional phytodiversity.

1Introduction

Biological diversity, considered as a variety of ecosystems, species, genomes, is the basis for the existence of the planet's biosphere [1, 2]. It ensures the maintenance of global cycles of elements, contributes to the stabilization of existing climatic conditions, and is an invaluable resource for solving a wide range of tasks facing humanity in the future [3, 4].

Conservation of biodiversity, including *in situ* and *ex situ*forms, should begin at the level of regions and local ecosystems, which are confined to habitats of rare species in their

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natural ranges. This implies a mandatory detailed inventory and subsequent monitoring of similar localities on the territory of regions for which the features of economic development that determine the level of anthropogenic transformation differ significantly [5].

As for the Samara region, a part of Middle Povolzhye, the anthropogenic transformation of the natural environment here has been carried out for centuries, but it reached its maximum level in the second half of XX. The powerful industrial complex formed here is highly diversified; its economic specialization is determined by the presence of objects of aerospace engineering, automobile production, oil production and oil refining, etc [6].The high level of anthropogenic transformation of the environment is also manifested in the conversion of up to 80% of the territory of the main part of administrative districts of the region into agrocenoses and the presence of the third in Russia largest dual-core urban agglomeration Samara-Togliatti, where more than 85% of the region population is concentrated.Under these conditions, the preservation of fragments of natural ecosystems was facilitated, among other things: - high contrast of the relief, unique for the Russian Plain, in which the amplitude of absolute heights exceeds 350 m; - the presence of 220 rivers and small streams, including the rivers Volga and Samara; - a complex structure of the soil cover, in which options are presented from gray forest soils to various chernozems, dark chestnut, solonetzes and solonchaks. The vegetation cover includes forest, meadow, steppe formations, vegetation complexes of river floodplains, marsh, rocky, solonetz and other communities with their inherent faunistic groups [6]. Having avoided destruction during plowing and other forms of anthropogenic transformation, natural complexes turned out to be confined to relatively small areas of territory within the space of agricultural land, dissected by highways and saturated with settlements of various sizes.The serious attention is paid to the conservation of biodiversity in the Samara region. Our region became one of the first regions in the Russian Federation where Biodiversity Conservation Strategy [6] was adopted, we were directly involved in its preparation.

The *in situ* conservation of the natural heritage is ensured by the regional system of especially protected natural areas, totally of 296.8 thousand hectares, including the protected areas of federal significance “Zhigulevsky State Natural Biosphere Reserve” (23.157 thousand hectares), the “Samarskaya Luka” National Park (127.186 thousand hectares) and the “Buzuluksky Bor” National Park (51.288 thousand hectares in the Samara region), as well as 211 natural reserves of regional significance (95.2 thousand hectares or 1.7% of the region area). Their distribution by the target content is: forest ecosystems - 86, forest-meadow - 7, meadow-steppe - 5, steppe - 49, forest belts - 14, wetland - 7, water - 36, etc.The territories have not received yet the status of protected areas are particularly need in search of valuable natural complexes, habitats of rare flora and fauna species of , which should be facilitated by the integration of ground and remote monitoring efforts.Traditional terrestrial (field) monitoring of biodiversity objects, as we know, provides information in a "point" version, its implementation for large areas is associated with significant labor and time costs [7]. At first glance, the use of remote sensing tools for the same purposes makes it possible to obtain spatially integrated information for vast territories with minimization of time costs. This position is confirmed by the results of studies carried out in different regions of the world, by the wide use of a number of coefficients characterizing the state of the earth's surface [8].At the same time, from the point of view of environmentalists, the possibilities of direct extrapolation of the experience of domestic and foreign work in the field of remote sensing for monitoring the ecosystems of the Samara region look very limited. This is due to the mosaic distribution of fragments of ecosystems of various types, their interpenetration, often in a very limited area [7-11].

The purpose of our report is to give a brief analysis of some results gained on initial stage of regional phytodiversity monitoring system development based on the integration of ground-based research and the remote sensing technologies.

2 Research methodology

Our complex research, launched in 2016, is being carried out on the territory of various administrative districts of Samara region. The work includes, on the one hand, the selection and detailed field survey of natural communities, the allocation of ground reference plots (etalons) within their boundaries, for which, in accordance with the program, ecological and biological information is collected. For reference plots we also fulfill the selection of available remote sensing materials, if necessary, supplementing with UAVs use, also classifiers adjustment or developing for recognizing vegetation patterns, and evaluating the effectiveness of planned tasks solvation.

3 Results and discussion

The results of a ground survey of the vegetation cover fragments for natural ecosystems by our botanists make it possible to reveal every year the presence of new, previously unrecorded species, including rare ones that supplemented the lists in the second edition of the regional Red Book [12].

We analyzed the confinement the number of natural reserves and higher plants species of the Red Book (2-nd edition) to the administrative districts of the Samara region (Fig. 1).

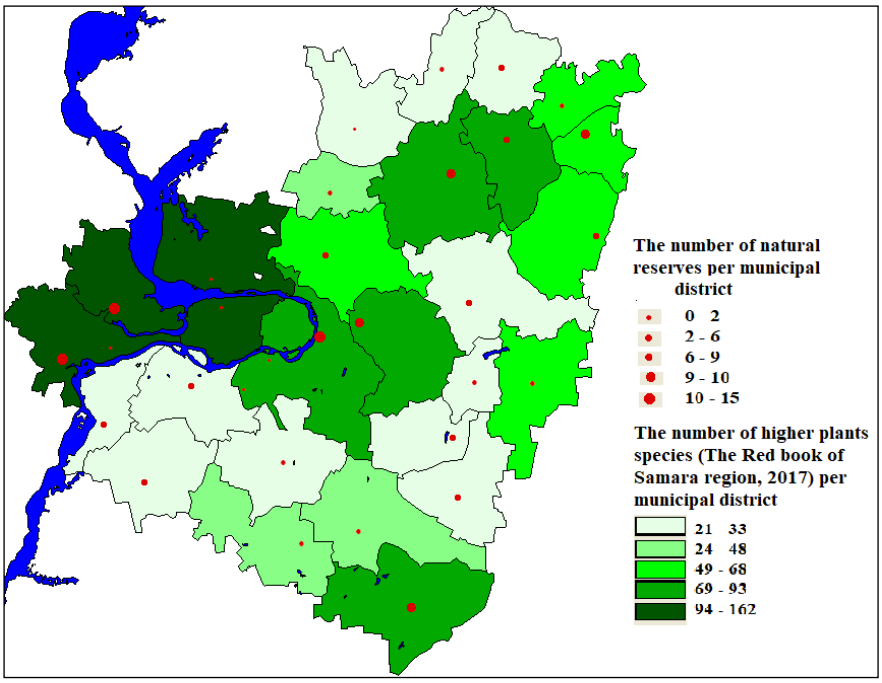

Fig.1. The spatial confinement of natural reserves and higher plants species of the Red Book number to municipal districts the Samara region.

To do this, the relevant primary information was entered as an addition to the database and used by us to build this map. This work helped us to visualize the spatial picture of individual territories value as refugia of rare components of regional phytodiversity, revealing a kind of “hot spots” on a regional scale. The integration of field and remote phytodiversity monitoring must be done for them primary.

The need to work on limited areas, with the selection of many standards and the construction of original or locally adapted systems of thematic classification, determines the specifics of problems that we had to solve. For the first time for ourselves, having started complex research aimed at developing a regional phytodiversity monitoring system, we formulated, based on world and Russian experience [10, 11, 13-15], an algorithm for selecting and using ground reference plots - sites for ground-based observations supplementing the RS data (Fig. 2). It includes such points as: - collection of information on the state of especially valuable natural communities in the course of a comprehensive ground survey and office data processing; – selection and cataloging of satellite data reflecting the diagnostic parameters and the time frame for their detection for the analyzed especially valuable natural communities; – classifier creation and training and its verification on remote sensing images for training and test data samples with ground surveys results.

The work according to the presented scheme was carried out for a number of target model objects - the first reference polygons identified by us (2016), fragments of various steppe communities (2017), shrub and tree vegetation of fallows (2018), fragments of forest belts and forest plantations of various species composition and age (2019), the obtained materials were involved in the processing of satellite images

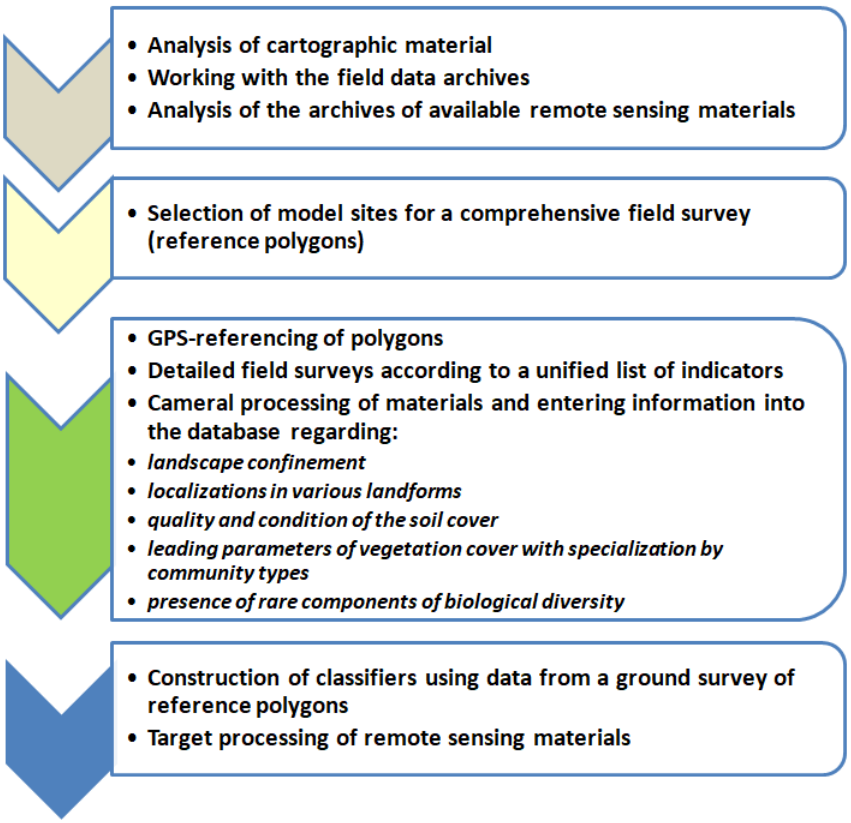

Fig.2. Step-by-step implementation of the algorithm for selecting and using ground reference polygons.

The step-by-step implementation of work according to the presented scheme was carried out for a number of model objects groups in 2016-2022 in two directions: - formation of a regional system of ground control plots (etalon polygons) supporting the work with remote sensing data (2016-2020); - assessing the possibilities of operational UAV use in

monitoring of plant communities state.The main characteristics of these investigations are presented briefly in the Tables 1 and 2.

Table 1. Creation of ground control plots (etalon polygons) system using space imagery materials.

Years	Etalon polygons	Solved problems and results
2016	Ground control plots (etalon polygons) in anthropogenically transformed ecosystems	Development of early prompt detection system of negative changes symptoms in soil and vegetation cover, being result of anthropogenic exploitation, extreme weather conditions etc. based on the integrated use of remote sensing data and ground survey of ecosystems. Objects of study: - overgrown fields formed on the plots withdrawn from circulation with the participation of different arboreal species (Nizhnenikolsky); - solonetzes and solonchaks, formed under the influence of a closely located system of ponds (reservoirs) (Pekilyanka); - exhausted lime quarry, with overgrowth of the bottom during the natural revitalization of the vegetation cover (Soksky karrier)
2017	Ground control plots (etalon polygons) - plots of field-protective and roadside forest belts with different species composition	Detection of forest belts as a specific spatial object and assessment of their state (categorization) for the usage in ecological and forest monitoring
2018	Ground control plots (etalon polygons) - parts of especially valuable natural communities typical of the Samara region and adjacent regions (steppe, forest, shrub)	Development of the regionally verified base of etalon polygons system for ground-based remote sensing tracking. For steppe ecosystems of different species composition, for the fist time in the region: - an approach was proposed for selecting reference sites based on preliminary clustering of a composite of NDVI indices for different dates within the growing season; - an algorithm for the spatial classification of steppe vegetation was chosen according to Sentinel-2 data; - territory classification of the protected area “Plot of the fescue-feather grass virgin steppe” and the adjacent territory, as well as part of the protected area “Urochische Mulin dol” was made. For forest ecosystems with different species composition: –the spatial classification algorithm of tree species according to Sentinel-2 composites was chosen; – the parameters of the classification algorithm were experimentally selected; - the comparative experimental studies were carried out, which made it possible to determine the most informative shooting seasons, individual images, as well as individual channels; - the resulting classifier was successfully applied to solve a practical problem - updating (clarification) of forest taxation data.
2020	Ground control plots (etalon polygons) - parts of natural steppe territories	The detection of burnt areas in steppes and determination of their age according to Sentinel-2 data based on the calculation of spectral indices between two successive images in time

The first group of data (Table 1) is devoted to our attempts to build the regional system of ground control plots (etalon polygons) on the base of integrating the data of ground

investigations and RS protocols.Table 2 presents the results obtained in different years by using UAV surveys to monitor the objects of the long-term studies previously carried out exclusively by ground-based methods. The first block of information refers to a valuable natural object, Strelnaya Mountain in the Zhiguli State Reserve, used for mass ecological excursions. Monitoring is aimed at assessing the state of vulnerable stony steppe plant communities on the mountain slope and identifying new (unauthorized) trails as a result of the exit of recreants from the excursion trail to the slope.

The second block of information is devoted to the experience of attracting UAV shooting to populations study of natural flora rarity plant *Paeonia tenuifolia*. The objects of monitoring are its multiple specimens ex situ cultured (Botanical Garden of Samara University) and a significant group of individuals previously translocated by botanists to natural ecosystems (to the polygons of rare plants reintroduction at natural reserves "Chubovskaya Steppe" and "Chubovskaya Kamenistaya Steppe").

Table 2. Some results of various natural objects Monitoring using UAVs.

Objects of monitoring	Years, solved problems and results
Excursion trail to Strelnaya mountain (Zhigulevsky State Reserve)	2019. The first experience of terrestrial and UAV-based monitoring integration. The identification of trampled areas of the rocky steppe slope with a high degree of accuracy. 2020. The surveying made it possible to obtain a series of digital images, which, taking into account the methodology developed in 2019, were processed by a number of classifiers in order to identify the best among them for detecting trails. The method of nearest neighbor K was used for retrospective analysis of various trail sections survey, showed recreational load increase in 2020 compared to 2019. 2021. Shooting the Mountain Strelnaya slope in autumn 2021 using a UAV made it possible to obtain digital images series, that were used for the detection of trails and the optimization of information obtaining on the of the surface of the steppe rocky slopes state. 2022. Monitoring of the state of unique communities in the area of influence of the excursion route on Strelnaua Mountain supplemented by processing of remote sensing materials, classification of displayed objects, retrospective analysis of surveys of various sections of the trail.
Polygons of rare plants reintroduction at natural reserves "Chubovskaya Steppe" and "Chubovskaya Kamenistaya Steppe". Botanical garden of Samara University	2020. The remote monitoring using an UAV (drone) was for the first time used In August 2020 in supplement to ground survey of rare plants reintroduced to nature (special markers were placed near each plant specimens of *Paeonia teniufolia*). 2021. UAV shooting of the dendrarium and the plot with the population group of rare plant (Paeonia tenuifolia) in Botanical garden. 2022. Monitoring of the population groups state for rare plants reintroduced to nature (Paeonia teniufolia).

4 Conclusions

Thus, in the Samara region, with its inherent high anthropogenic transformation of landscapes, the preserved natural communities are highly fragmented. Their identification among anthropogenic spaces also as subsequent field surveys are of highly labor- and time-cost. This situation determines the relevance of remote sensing technologies use to identify and monitor the valuable plant communities state.

The effective use of remote sensing data in biomonitoring undoubtedly needs the presence of a of regional reference (etalon) polygons system. Such a system has been worked

out since 2016 by specialists in the field of ecology, botany and geoinformatics, Samara University. The main results of our joint efforts are regionally verified classifiers that allow the most efficient processing of available remote sensing materials corresponding to various types of natural and anthropogenically transformed vegetation plots in the Samara region.

We also confirmed the point of view [for instance, 14, 15] regarding the high efficiency of using UAVs to identify and analyze the anthropogenically transformed and natural areas state, including small nature localities.

So, the efforts unification of different profiles specialists and the integration of classical and innovative technologies represent the most realistic way to study, monitor and preserve regional phytodiversity.

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