Ecological networks as a means for maintaining the sustainability of agroecosystems in Bryansk Oblast

Alina Nekrich*

Institute of Geography of the Russian Academy of Sciences, 29, Staromonetny lane, Moscow, 119017, Russia

Abstract. Bryansk Oblast is one of the most vulnerable regions to the effects of agricultural and industrial activities resulting in ecosystems' sustainability decreasing. For the last decade, agricultural sector has been developing rapidly and now overtakes the industrial one. The dynamics of agricultural lands has positive trends in spite of the rising fragility of agroecosystems exposing them to further degradation. The goal of the study is to show a spatial distribution of the most vulnerable ecosystems involved in agricultural use on the territory of Bryansk Oblast and to propose an optimal structure of ecological networks that is able to support landscape sustainability during agricultural activity. Based on the technique for identifying the combination of agroecosystems with destabilizing features and protective properties, four ecological belts that form ecological networks were revealed. These belts consist of 65 sites of high nature concentration. The results of this research correlate well with the modern territorial planning scheme of Bryansk Oblast. Ecological networks are viewed as a necessary element of this scheme, as they will be able to mitigate the environmental impact of agriculture and to maintain the sustainability of agroecosystems at both the regional and intraregional level.

1 Introduction

Bryansk Oblast is a part of the East European Plain and is located mainly in the forest-steppe zone within a well-developed river network [1]. Occupying fertile agricultural lands Bryansk Oblast accounts for 20% of the Gross Regional Product and takes the 1st and the 2nd places on industrial potato, cattle, and beef production in Russia [2]. Agroecosystems are the vast majority territories of Bryansk Oblast and their area is still increasing. According to statistical data, over 54% from the total area of the oblast or 1876.1 thousand ha are used for agriculture, of which 1178 thousand ha as arable land, 25.8 thousand ha as permanent crops, 205.6 thousand ha as hayfields, 345.6 thousand ha as pasture land, and 121.1 thousand ha are abandoned agricultural lands [2]. Agroecosystems are shaped by natural landscapes and include deeply fragmented natural sites with protective and destabilizing features [3]. The original forest cover does not exceed 25% that is unlikely can be combined with

* Corresponding author: a.s.nekrich@igras.ru

environmental sustainability [1]. Besides, agricultural fields with destabilizing features are larger than reserved lands (RLs) and natural protected areas (NPAs) in the studied oblast [3].

As a rule, agricultural activity damages natural landscapes and affects territories with protective properties [1, 2, 4]. The land degradation takes place over 16 thousand ha, including 12 thousand ha of non-remediated lands [2]. In order to prevent such a harmful tendency and to stop the continuous loss of the natural environment, the components of agroecosystems should be analyzed according to their functions and properties [5]. It means that areas with destabilizing features within the agroecosystems should be rational placed not only in the natural landscape, but need to be considered as a significant element of the modern territorial planning scheme (TPS) of Bryansk Oblast. It can be achieved through construction of ecological networks (ENs). As R. Jongman and J. Pungetti note [6], ENs are the basis of ecological components providing the balanced environmental conditions for the existence of ecosystems in contemporary landscapes. The concept of ENs is more important for the lands in agrarian-oriented districts as agroecosystems tend to further degradation [3-8]. Creation of ENs will make possible to strengthen intercomponent links between natural objects with protective features, such as natural forests and forest plantations, lands under woody-shrub vegetation, ponds, gully meadows, protected areas, hayfields, pastures, perennial plants, and arable lands under perennial crops on the territories with a high fragmentation of land use [3]. In turn, ENs should be a part of TPS of Bryansk Oblast, as they are able to maintain agroecological systems in a balanced state during the development of the industrial, transport, and social infrastructure.

Given the above considerations, author focuses on the aim of the research – to show a spatial distribution of the most vulnerable ecosystems involved in agricultural use on the territory of Bryansk Oblast and to propose an optimal structure of ecological networks that is able to minimize harmful consequences during agricultural development.

This aim can be achieved through solving the following tasks:

- to identify a contemporary spatial distribution of the structural elements of agroecosystems and their environmental condition,
- to determine the location of sites with protective features that are the most acceptable for ENs creation in the current structure of land use and in the modern TPS,
- to find out the role of ENs in reducing the environmental impact of agriculture.

The research has a practical meaning not only for Bryansk Oblast, but also for similar agrarian-oriented territories across the world. Also, the research is a part of a series of case studies are conducted by the author in Russian regions.

2 Materials and methods of the study

The study is carried out by employing several conceptual and practical approaches elaborated at the Institute of Geography of the Russian Academy of Sciences [9, 10, 11], Orel State University named after Turgenev [12], the All-Russian Research Institute of Agriculture and Soil Protection from Erosion [13], and Ivan Petrovsky Bryansk State University [14]. These approaches are combined by the general principles: the placement of ecosystems with protective and destabilizing features within the territory of agricultural activity has to be environmentally balanced. The sustainability of ecosystems is considered according to the scientific work [15]. The data on environmental situations, as well as satellite images, statistical and cartographic information were gathered from open sources [1, 2, 8, 16-22]. The author has applied landscape analysis, maps, field data, and has sudied reports on environmental conditions to show features of a spatial distribution of agroecosystems on the territory of Bryansk Oblast.

The author has focused on studying the features of the spatial distribution of the structural elements of agroecosystems: agricultural land, meadow, forest, natural water objects, and

elements of the buffer zone for wildlife protection. The environmental condition of agroecosystems in Bryansk Oblast was detected in the previous author's works [3, 4]. The leading factors of agroecosystems dynamics are published in the author's papers [23, 24]. These data were used in order to solve the task of the research – to identify a spatial distribution of the structural elements of agroecosystems with protective features in the current structure of land use and TPS. The structural elements of ENs meet the following conditions: to maintain a territorial balance between agricultural development and biodiversity conservation and should be included in the modern TPS of Bryansk Oblast. The main criteria of biodiversity conservation sites were chosen according to the review [25]. As a result, four representative ecological belts have been identified at the intraregional level of Bryansk Oblast. The land use analysis, detection of agroecosystems distribution, and identification of the structural elements of ENs were performed by means of ArcGIS (ESRI).

3 Results of the study

While the study was running, four ecological belts that form ENs consisting of 65 sites of high nature concentration were identified. It was revealed that ENs are placed in the districts with different environmental conditions [3]. All ecological belts are mosaic. They are extending in the meridional direction along the large river basins. The distance between the structural elements of ENs varies to both the meridional and natural landscapes borders. These settings can be explained by landscapes trajectories (Figure 1).

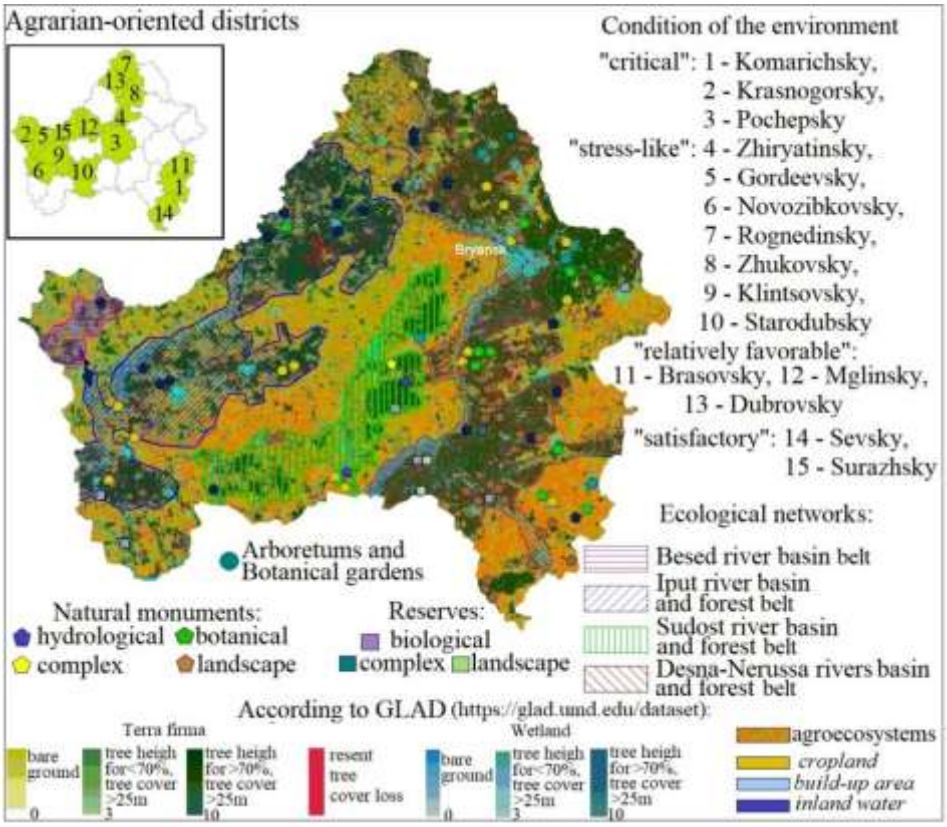

Fig 1. A spatial distribution of the most vulnerable ecosystems involved in agricultural use and the location of ecological networks on the territory of Bryansk Oblast.

As was mentioned above, ENs have to be created according to the basic concepts [5, 6]. These concepts are also recognised as «polarized landscape» and assume that ecological nets consisting of settlements and protected areas are overlapped on agricultural lands. The size and boundaries of polarized landscape zones vary depending on the environmental condition. Reserves and other areas with protective functions lie on the one side, the city centers and industrial areas – on the other side and are considered as an equally important polar part of the environment [26]. In general, the main principle is that the ecological cores of ENs should be distanced from the areas of human activities in order to prevent biodiversity loss, as well as to enhance landscapes sustainability [5]. The proposed ENs consist of the following elements: core areas, ecological nodes, ecological corridors, buffer zones, and remediated areas included in ecological belts [5, 6]. The boundaries of ecological belts were identified according to habitats of rare species, territories of the main value for biodiversity conservation, and objects of high nature concentration [3, 4]. As a rule, the core areas are fixed to the natural environment objects such as RLs and NPAs and classified as territories of high importance for wildlife existence; the ecological nodes are compiled to forests with protective features that contributes to conservation of landscape and biological diversity; the ecological corridors are spaced to river valleys, floodplains, landscape complexes on low and high terraces, and watershed; the buffer zones include low-value lands transformed by man-made activity; the remediated areas include territories that have lost their original environment features and now are subject to soil enrichment and recultivation.

One of the greatest ecological belts stretches within *the Iput river basin*. Its area is 613 thousand ha. The belt runs through the multifunctional TPS with large centers of municipal districts [1]. From north to south, the environmental condition is changed from relatively favorable to stress-like. Fields with protective features in the structure of agroecosystems exceed areas with low-environmentally sustainable features in 1.5 times [3]. From north to south, deflation and erosion cover from 10% to 30% of agricultural lands. Soil acidification occurs on 90% of arable land [27]. The average acidity of arable land (pH) ranges from 5.4 to 5.2 [28]. Emission of SO_2 varies greatly (from 0.7 to 9 tons). The most polluted sites are located close to industrial zones. CO ranges between 0.2 and 13.0 tons, NO varies from 0.2 to 32.3 tons, and hydrocarbons entering the atmosphere range from 29 to 213 tons per year [2, 3]. To the south, the belt is placed close to the federal railway lines and highways roads.

Forest area is highly fragmented within the ecological belt. In the north, forest is mostly used for production of assortments, excluding forests are placed in NPAs [3]. The core areas are attached to Iputsky Porog, Petrovskoe bog, and a part of Kletnyansky reserve. The ecological nodes are compiled to large reserved lands, forest massives, oak groves, and lakes. The territories lying along Iput river can be taken into consideration as the ecological corridors. The buffer zones contain disturbed agricultural lands. The remediated areas are placed close to forest lands. In the south, forests are located unevenly. The sites with protective functions have hydrological and complex nature. The Blue Vir, Iputsky Natural Park, Khutor Lubin, Klintsovsky reserve, Priiputsky heights, Zalomenje lake, Golubovsky spring, and Dekhanovo can be viewed as the core areas. The ecological nodes are located in oak forests. The buffer zones contain areas of economic activity and separate agricultural lands from the sites of ecological equilibrium. The ecological corridors include floodplain oak forest growing near the rivers. The remediated areas are situated at a distance from the rivers and don’t create a continuous zone.

The ecological belt over *the Sudost river basin* is located in the central part of Bryansk Oblast. This belt covers 560 thousand ha. The territorial imbalance between agricultural lands and conservation sites is the most visible. The central part of the belt is included in the multifunctional TPS with gas pipelines, federal railway, and highways roads. The total area with protective features is not enough for a sustainable environment [3]. The environmental condition of agroecosystems in the central part of the belt is critical; to the north and south –

is stress-like. Deflation and erosion occupy 40% of arable land [27]. The polluted waters include Fe, NH_4NO_3, and NO_2 [2]. MACs are closed to 2. The soils contain less than 2% of organic matter. Soil acidification occurs on 70% of arable land. The average acidity of arable land (pH) is 5.6 [28]. The emission of SO_2 ranges from 0.1 to 9.7 tons, CO – from 90 to 100 tons, NO varies from 6.0 to 48 tons, and the hydrocarbons entering the atmosphere range from 75 to 223 tons [2, 3]. Among the core areas are natural monuments, biological reserves, and arboretums: Ramasukhsky reserve, Menagerie, Saint lake, Markovskie Gori, Vably slopes, and Red Rog arboretum. The ecological nodes include Memorial Forest, Semetskaya and Desyatukha oak groves. The ecological corridors can be seen laying on floodplain's meadows along the rivers. The buffer zones are placed on pastures and arable land. Forest is used for production purposes [1, 2].

The next ecological belt occupies 490 thousand ha and stretches along *the Desna-Nerussa rivers basin.* The belt is integrated into the multifunctional TPS with large cities, federal railway lines, highways roads, logistics complexes, and gas pipelines [1, 2]. To the north, the environmental condition is stress-like. MACs of ammonium nitrogen in the river waters reach 2. The soils do not meet hygienic standards for sanitary and chemical indicators [2, 3, 28]. Over the Nerussa river basin the lands with protective features are placed in agrarian-oriented districts with critical, relatively favorable, and satisfactory environmental conditions. Deflation and erosion cover from 10% to 40% of lands [27]. MACs of nitrogen ammonium and nitrite in the river waters are well above 2. The average acidity of arable land (pH) varies from 5.2 to 5.6 [28]. In 2022, SO_2 emission reached from 0.8 to 9.7 tons, CO ranked from 0.2 to 9.4 tons, NO varied from 0.3 to 4.5 tons, and hydrocarbons entering the atmosphere ranged from 0.2 to 6.2 tons [2, 3]. Wooded lands are highly fragmented. Designated functions of forest are soil, water, and biodiversity protection [5]. According TPS, majority forests are predominantly under agricultural or urban land use [1, 2]. The core areas contain Lopandinskie Kolki, Vasiliev arboretum, Pechnoye, Melovitsky slopes, Vodopoymennoye and Studimlskoe bogs, Melovitsky spring, Kuliga natural boundary, Kholmechsky spring, Nikolskaya Dacha, Karbonel natural boundary, Shvedchiki, Streletskaya, and Sevskie slopes. The Brasov oak forests, Vladimirovskaya Dubrava, Forest with rare plant species, Khinelsky and Zeleninsky forest, and Sevskaya Dubrava are viewed as the ecological nodes. The ecological corridors pass through the Upper Kalakhva river valley and Krapivna river floodplain. The buffer zones include abandoned pastures and haymaking.

In the central part of the belt, forest and green areas over cities have protective functions. The core areas include Orekhovoe lake, Semenovskoe bog, Bechino natural monuments, Saint and Bezdonnoe lakes, and Valuable lands. The ecological nodes are Sokoliny Bor and forests. The ecological corridors are placed on floodplains meadows along the rivers. Mostly sites with protective functions correspond to the southeastern part of Bryansk Oblast. Among them are hydrological and biological natural monuments, arboretums, and botanical gardens.

To the west, the ecological belt is located over *the Besed river basin*. The number and size of natural objects with protective functions are the smallest in Bryansk Oblast. The environmental condition here is critical. The whole area of the belt doesn't exceed 50 thousand ha. The belt includes regional highways nets and the only one municipal center [3]. Forest area with protective functions is highly fragmented [1]. Most agricultural lands are disturbed by deflation and erosion [3, 27, 29]. MACs of iron reach 3 in the river waters. The average acidity of arable land (pH) is 5.3 [28]. The total emission of SO_2 is estimated to be 0.5 tons, CO ranks from 4.6 to 12.0 tons, NO varies from 0.3 to 9.7 tons, and hydrocarbons entering the atmosphere range from 33 to 73 tons per year [3]. The number of core areas, ecological corridors, and buffer zones is insufficient. There are only 3 objects with protective functions can be viewed as the core areas for ENs construction: Besed-Kovpita, Saint lake, and Kozhanovskoe lake. The natural restoration of abandoned agricultural lands would enable to compensate this protective element shortage [3, 23]. Due to their potential

ecological functions and territorial location, they have a potential to be included in ENs over time.

It should be noted that the main problem occurring during ENs creation is the lack of links between the ecological cores and nodes owning to increasing agricultural activity, as well as urban and transport network development within the territories of the ecological corridors [30-38]. The agro-industrial complex, urban and rural settlements, and related infrastructure facilities are often located within the buffer zones. Agricultural lands (particularly arable land, pasture, and permanent crops) are also found there. Besides, many NPAs have lost their protective status [4]. However, they could be involved in the structure of ENs, as they had a special environmental protection status in the past [39-40].

4 Conclusions

The results obtained from the study allow the author to make the conclusions:

1. Due to intensive agricultural development, the environmental condition on the territory of Bryansk Oblast has locally reached critical and stress-like values. The resistance of lands to agricultural pressure is falling that accelerates the extension of areas with destabilizing features. The creation of ENs is able to mitigate this negative trend by means of rational locations of sites with protective features in the current structure of land use and in TPS. Each landscape unit is related to the present-day structure of land use and landscapes, TPS, and numerous systems of links occurring between elements of the landscape placed in different environmental conditions. Taking into account these features, ENs have to consist of core areas, ecological nodes, ecological corridors, buffer zones, and remediated areas. The number and the size of such elements have to meet the environmental condition of districts where they are located and are subject to agricultural impact.
2. Based on the technique for identifying the combination of agroecosystems with destabilizing features and protective properties, four ecological belts that form ecological networks were revealed. Each belt is a significant section of ENs that can be constructed in the studied agrarian-oriented districts. These belts are crucial for the sustainable structural, functional, and spatial organization of Bryansk Oblast. They stretch along the river basins and consist of sites are considered as the structural elements of ENs. They support links arising between sites with protective features through interaction of core areas, ecological nodes, ecological corridors, and landscape fields with protective functions. The area of river valleys is of great importance for landscape and biological diversity protection. An inverse relationship between spatial distribution of the structural elements of agroecosystems and their environmental condition has been found out; it is matched to the structural elements of ENs. Ecological networks should be integrated in the process of economic development for the implementation of the environmentally-oriented management in Bryansk Oblast.

In order to successfully maintain the functioning of agroecosystems it is necessary to exceed the area of spatial protection by organizing the intraregional ENs. The most important step is to create a network of forest that could potentially be included into transboundary nature reserves. It has become increasingly clear that abandoned agricultural lands have to be converted to reserved lands. For example, the conversation of arable and pasture lands with low productivity to the category of protected lands is one of the effective methods for agricultural production optimization. The obtained results can be used for TPS optimization and organization of environmental monitoring systems. Ecological networks could find a role as a one of the significant means to solve the problem of environmental fragmentation in agrarian-oriented regions around the world.

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