DOI: 10.17951/b.2023.78.0.97-114

ANNALES
UNIVERSITATIS MARIAE CURIE-SKŁODOWSKA
LUBLIN – POLONIA

VOL. LXXVIII SECTIO B 2023

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Potentially Important Areas for the Eurasian Lynx (*Lynx lynx*) as a Basis for Determining the Structural Elements of the Eco-Network of the Transcarpathian Region in Ukraine

Potencjalnie ważne terytoria występowania rysia euroazjatyckiego (*Lynx lynx*) jako podstawa do wyznaczenia elementów strukturalnych ekosieci regionu Zakarpacia na Ukrainie

Abstract: The purpose of the publication is to indicate potentially important areas for the presence of the Eurasian lynx (*Lynx lynx*) within the Transcarpathian region in Ukraine using GIS modeling tools to optimize the network of protected areas. The modeling consisted of a preliminary analysis of the following five parameters that are important for the life of the species: type of land cover, proximity of non-forest biotopes to forest biotopes, high-altitude bioclimatic zones, degrees of relief dissection, distance from settlements and roads. A comprehensive GIS analysis of these parameters made it possible to establish that the total area of territories that are potentially suitable for the presence of the Eurasian lynx within the Transcarpathian region is 192.6 thousand hectares, and covers about 9.9% of the territory of the region. The most suitable areas are concentrated in the mountainous southeastern part of the region within the orographic ecoregion of the elevated dissected highlands. Within the modeled habitats, there are often places where real signs of the species' distribution have been recorded. In the second stage of the research, a cartographic model "Territories of the potential presence of the Eurasian lynx (*Lynx lynx*) and key areas of the regional ecological network of the Transcarpathian region" was obtained, where population, reproduction and other areas, as well as the degree of nature protection in these areas, were established.

Keywords: Eurasian lynx (*Lynx lynx*); ecological corridor; Transcarpathian region; protected areas

Abstrakt: Celem publikacji jest wskazanie potencjalnych terenów występowania rysia euroazjatyckiego (*Lynx lynx*) na obszarze Zakarpacia na Ukrainie z wykorzystaniem narzędzi GIS. Wyniki tych badań mogą zostać wykorzystane do optymalizacji sieci obszarów chronionych w tym regionie. Modelowanie polegało na wstępnej analizie następujących pięciu parametrów istotnych dla życia rysia: rodzaj pokrycia terenu, bliskość biotopów nieleśnych do lasu, wysokogórskie strefy bioklimatyczne, stopień rozczłonkowania rzeźby terenu, odległość od zabudowy i dróg. Kompleksowa analiza GIS wskazanych parametrów pozwoliła ustalić, że łączna powierzchnia terenów potencjalnie odpowiednich do życia rysia euroazjatyckiego na Zakarpaciu wynosi 192,6 tys. ha (9,9% terytorium regionu obwodu). Najbardziej odpowiednie obszary są skoncentrowane w górskiej, południowo-wschodniej części regionu, w ekoregionie orograficznym znacznie rozczłonkowanych pasm średniogórskich. W obrębie modelowanych siedlisk często występują miejsca, w których odnotowano rzeczywiste ślady występowania gatunku. W drugim etapie badań uzyskano model kartograficzny „Terytorium potencjalnego występowania rysia euroazjatyckiego (*Lynx lynx*) oraz kluczowe terytoria regionalnej sieci ekologicznej Zakarpacia". Na podstawie tego modelu wskazano obszary funkcjonowania i reprodukcji populacji rysi oraz stopień ochrony przyrody w tych obszarach.

Słowa kluczowe: ryś euroazjatycki (*Lynx lynx*); korytarz ekologiczny; region Zakarpacki; obszary chronione

INTRODUCTION

Transcarpathian region is located in the southwest of Ukraine. In the north it is bordered by Lviv, in the east by Ivano-Frakivsk oblasts of Ukraine, in the south – by Romania, in the southwest – by Hungary, in the west – by Slovakia and in the northwest – by Poland. About 80% of the territory of this land is occupied by mountains, creating from the southwest to the southeast the Vododilnyi mountain range, the Gorgany, the Svydovets, the Chornohora, the Polonynskyi range, the Rakhiv Massif and the Volcanic Carpathians. The southwestern part of the oblast is covered with the Transcarpathian Lowland (100–120 m a.s.l.). The Tisza (the Danube's left tributary) is the longest river. The longest tributaries are the Borzhava, the Rika, the Tereblia and the Teresva. The next largest rivers are the Latorytsia and the Uzh which fall into the Bodroh river.

Fragmentation of natural habitats due to the development of settlements, transport infrastructure and the creation of new economic facilities significantly impairs the migration possibilities of fauna, especially mammals. The consequence of this is the complication of genetic exchange and the general violation of the normal conditions for the existence of species, which leads to a weakening of populations and to a reduction in their numbers. Thus, the Eurasian lynx (*Lynx lynx*) has become rare in Ukraine, with one of the distribution areas in the

Carpathian region. Despite the fact that it has been included in the Red Book of Ukraine since 1994 (Shcherbak 1994), the population has not significantly increased. One of the reasons is the decrease of the habitat area of this species. Therefore, in 2021, it was included in the Red Book of Ukraine (2021) with the "vulnerable" status.

To date, the Order of the Ministry of Environmental Protection and Natural Resources of Ukraine No. 595, dated September 15, 2021, approved the "Action Plan for the Conservation of Eurasian Lynx in Ukraine" (hereinafter referred to as "Plan"). According to the Annex of the "Plan", the population of lynx species in the Ukrainian Carpathians ranges from 200 to 350 individuals, and the population density is 8–15 individuals per 1 thousand square kilometres. For comparison, the lynx population density in the Romanian Carpathians is estimated at 13–16 individuals per 1,000 square kilometers (1,500–1,800 individuals in total) (Losif et al. 2022), in the Slovak Carpathians – at 8–13 (250–400) (Kubala et al. 2017), in the Polish Carpathians – at 21 (about 411) (Hackländer et al. 2022), and in Hungary – at 1–2 (10–25) (Kubala et al. 2021). In all countries of the Carpathian region, the Eurasian lynx is protected under national and international legislation. Today, this species is on the IUCN Red List, included in Appendix II of CITES and Appendix III of the Bern Convention. Accordingly, research aimed at identifying the habitats of the species for the purpose of their further protection is relevant. They include a preliminary study of the potential suitability of biotopes for the presence of Eurasian lynx, monitoring of real places of its settlement and migration routes. Modern scientific publications (Hochevar et al. 2020; Pushkash et al. 2021) are mainly related to the development of a system for monitoring the population of the Eurasian lynx, the study of the behavioral characteristics of the species (Filla et al. 2017; Jones et al. 2022), development of mechanisms to preserve its habitats (Kubala et al. 2017; Hochevar et al. 2020), etc. Among the measures aimed at overcoming the negative consequences of habitat fragmentation is the development of a network of nature protection areas and the formation of an ecological network with a system of eco-corridors (Teslovych, Krychevska 2021).

Currently, the process of developing approaches to monitoring the population size of the species and its protection continues in Ukraine (Pushkash et al. 2021; World Wildlife Fund of Ukraine 2022). In 2010, a group of specialists carried out modeling of ecological corridors (for the Eurasian lynx, in particular), using GIS technologies: Turkivskyy (between the regional landscape park "Nadsyanskyy" and the National Natural Park "Skolivski Beskydy") and Bukovynskyy (between the National Natural park "Vyzhnytskyy" and general zoological reserve "Zubrovytskyy") (Deodatus, Protsenko 2010, p. 65).

It has to be noted that the Eurasian lynx is an environment-creating species and one of the species most sensitive to fragmentation (Deodatus, Protsenko 2010). That is why it is important to ensure environmental protection management in the areas of its stay and opportunities for migrations.

The purpose of our study is to indicate potentially suitable areas for the Eurasian lynx within the Transcarpathian region using GIS tools. In the future, these areas will become the basis for clarifying the boundaries of certain key areas (main elements of the ecological network according to the Law of Ukraine "On the Ecological Network of Ukraine" No. 1864-IV of 24.06.2004) and more clearly defining the boundaries of ecological corridors.

MATERIALS AND METHODS

To achieve the goal, we used the main methodological techniques and principles proposed by a group of experts (Deodatus, Protsenko 2010) and outlined in the manual *Creation of Ecological Corridors in Ukraine*. According to this methodology, ecological corridors are proposed to be identified using GIS through a comprehensive assessment of various environmental components that are important for the existence of populations of model species in a particular natural region. For example, for the Carpathian Mountains, one of these model species is the Eurasian lynx. We have analysed the following five parameters to identify its habitats: 1) types of land cover, 2) proximity of non-forest ecosystems to forest biotopes (in meters), 3) high-altitude bioclimatic zones, 4) the degree of vertical dissection of the relief, 5) distance from settlements and roads (Deodatus, Protsenko 2010).

In the presented study, we adapted this technique to a smaller scale (1:500 000) using QGIS 3.16.8 software. To analyze the first and second parameters and create the corresponding raster layers, we used spatial data from the Global Land Analysis and Discovery (GLAD) laboratory in the UTM Zone 34/WGS84 coordinate system with a cell size of 30×30 m (Potapov et al. 2022). We replaced the parameter "ratio of forest areas and meadows in the vicinity of 250 m (in%)" with the parameter "proximity of non-forest ecosystems to forest biotopes (in meters)", which made it possible to determine the most suitable biotopes according to this indicator for the presence of the Eurasian lynx tools available for the specified software. SRTM data in the UTM Zone 34/WGS84 coordinate system with a cell size of 30×30 m was used to analyze the third, fourth, and fifth parameters and create the corresponding raster layers.

Geoinformation analysis of each of the parameters made it possible to construct five raster layers, the cells of which contain an assessment of the suitability of each of the five parameters of the territory for the Eurasian lynx on a scale from 0 to 100. A description of the resulting raster layers is presented below in the "Results and Discussion" section. For the purpose of an integral assessment of the suitability of biotopes for the presence of the Eurasian lynx, a combined raster was created using a weighted overlay analysis. This analysis involved the overlay of five raster layers, followed by the calculation of the sum of their cell values and the reclassification of the result on a scale from 0 to 100. At the same time, all indicators, except the distance from settlements and roads, were considered equivalent and a weighting factor, equal to 1, was applied to them. A weighting factor, equal to 3, was applied for the distance assessment layer from the populated areas and roads, since the Eurasian lynx is a very sensitive species to human presence. This weighting factor was proposed by zoologists who developed the methodology we use in our research (Deodatus, Protsenko 2010, p. 64). We brought the obtained values of the integral suitability of biotopes for the species to a point scale from 0 to 100 and reflected on the corresponding map (Fig. 1), which indicates six gradations of territories: from "absolutely unsuitable for lynx habitation" (suitability is 0 points) to "most suitable for lynx habitation" (suitability – more than 71 points).

In order to determine the most valuable habitats, on the map of potentially important areas for the presence of the lynx, the point localities of the real habitats of the species, recorded by zoologists during field and instrumental research, were plotted (Bashta et al. 2004; Animalia database 2023). Such critically valuable habitats, in our opinion, should be protected at the state level within nature protection areas of different status.

According to the proposed methodology (Deodatus, Protsenko 2010, p. 64), the area of Eurasian lynx, which received points higher than 55, can form population and reproduction areas. For population sites, the minimum area can be 6.0 thousand hectares, for reproduction – 1.2 thousand hectares. Areas that are unsuitable for permanent residence or reproduction of the species and which can only be used for migration have an area of less than 1.2 thousand hectares. Considering this criterion, we divided the relevant habitats into three groups and presented them on the corresponding map scheme (Fig. 2).

For the spatial analysis of the state of protection of identified habitats and potentially important areas, layers were added with the boundaries of protected areas of national and international importance, as well as key areas outlined on the schemes of scientists (Brusak et al. 2006; Krychevska et al. 2010; Turys et al., 2015). This have made it possible to optimize the existing network of protected areas by identifying areas for its possible expansion.

RESULTS

According to the chosen methodology, we analyzed five parameters that are important for determining potentially suitable areas for the presence of the Eurasian lynx: types of land cover, proximity of non-forest ecosystems to forest biotopes, altitudinal bioclimatic zones, the degree of vertical dissection of the relief and distance from settlements and roads. The main methodological techniques and the obtained results for each of the parameters are described below.

To create a raster layer based on the mentioned methodology (Deodatus, Protsenko 2010, pp. 58–60) characterizing the suitability of land cover types for the presence of lynx, we used spatial data from the Global Land Analysis and Discovery (GLAD) laboratory with a cell size of 30×30 m (Potapov et al. 2022) for the territory of the Transcarpathian region and partially adjacent regions and countries. The raster image was reclassified so that each cell-contained information about one of the given land cover classes: coniferous forest, deciduous and mixed forest, meadows, including shrubs, arable land, settlements, large watercourses and reservoirs that can be taken into account at the raster layer resolution. Among the vector layers of OpenStreetMap, we have selected linear objects that represent railways, highways, main and secondary roads that cannot be taken into account at the resolution of the raster layer, and combined them into one raster layer. As a result, two raster images (with planar and linear types of objects) were obtained, which contain information about 10 types of land cover (coniferous forest, deciduous and mixed forest, meadows, including shrubs, arable land, settlements, reservoirs, railways, highways, main and secondary roads, watercourses). Each of the specified types was evaluated according to its suitability for the stay (life activity) of the Eurasian lynx. This scientific publication used the assessment proposed by zoologists who developed the methodology (Deodatus, Protsenko 2010) presented in Tab. 1.

Considering the scale of the study, we have rated all forest ecosystems of the region at 100 points. At the same time, we note that the lynx in the Carpathians prefers native coniferous forests, often occupying areas of natural transition zones between broadleaf and coniferous forests.

The main food of the lynx are roe deer and deer, smaller species (birds and mouse-like rodents) (Jędrzejewski, Jędrzejewska 1993; Lushchak et al. 2006; Odden et al. 2006; Zhyla 2012). In search for food in summer, the lynx reaches the meandering forest zone and subalpine meadows, and, after snow appears, descends into valleys. Accordingly, meadows, including shrubs, are rated at 10 points. Since the species is difficult to adapt to the transformed environment, other types of land cover (large watercourses, areas with residential and transport

Tab. 1. Land cover types of the Transcarpathian region suitable for Eurasian lynx and their conservation status

No.	Land cover types suitable for the Eurasian lynx	Area* (thousand hectares)	Lands that are part of the territories of the nature protection areas*	
			thousand hectares	%
1	Broadleaf forests	397.6	46.6	11.7
2	Mixed forests	302.0	90.2	29.9
3	Coniferous forests	75.7	29.7	39.2
	Forest lands in total	*775.3*	*166.2*	*21.4*
4	Meadows with shrubs	295.1	21.6	7.3
5	In total	1,070.4	188.1	17.6

*obtained according to our calculations based on raster spatial data of the Global Land Analysis and Discovery (GLAD) laboratory
Source: Authors' own study.

infrastructure, arable land) are defined as "absolutely unsuitable" and, accordingly, are evaluated at 0 points.

GIS analysis of the raster layer of land cover types in order to detect potentially suitable ecosystems for finding the lynx made it possible to establish the following. In general, 1,070.4 thousand hectares are classified as such ecosystems, which is 83.9% of the area of the region. Among them, forest ecosystems stand out (775.3 thousand ha; 60.8% of the territory of Transcarpathia) and meadows, incl. with shrubs (295.1 thousand ha; 23.1% of the territory of the Transcarpathian region). Consequently, broad-leaved, coniferous, and mixed forests were distinguished among the forest types of land cover (Tab. 1). For meadows, including shrubs, we attributed mountain subalpine and alpine, secondary meadows, as well as agricultural land, with the exception of arable land.

The types of land cover that are absolutely unsuitable for presence of lynxes include: significant watercourses and reservoirs that are barriers to the movement of the species (18.4 thousand hectares; 1.4% of the area of the region), as well as areas with dense residential, transport infrastructure and arable land (187.5 thousand hectares; 14.7% of the territory of the Transcarpathian region).

To create a raster layer that characterizes the proximity of non-forest ecosystems to forest biotopes (in meters) using reclassify by table tool, the target cells of the land cover raster layer containing information about forested areas, were assigned the value of 1, and all others (non-forest) – 0, respectively. Using the tool "proximity (raster distance)" created a buffer of 250 m (by georeferenced coordinates) around the target cells. The value of the raster cells that fall within the boundaries of the buffer around forested areas was reclassified in such a way as to group them into 3 categories divided by equal distance. As the distance increases, the level of suitability of the territory for a species decreases. Accordingly, we classified non-forest ecosystems located at a distance of more than 250 m from forest ecosystems as completely unsuitable. The value of proximity of non-forest ecosystems to forest biotopes was estimated as shown in Tab. 2.

Tab. 2. Assessing the importance of the proximity of non-forest ecosystems to forest biotopes*

	Value of proximity of non-forest ecosystems to forest biotopes (meters)			
	0	0–83	83–166	166 ≤
Score (points)	100	50	10	0

*biotope is an area of uniform environmental conditions providing a living place for a specific assemblage of plants and animals
Source: Authors' own study.

It should be noted that the buffer around forested areas can include not only meadow ecosystems, but also significantly transformed ecosystems as a result of economic development: arable lands, settlements, etc. However, when calculating the integral biotope suitability index, such raster cells will receive the lowest values, according to the parameters "land cover types and distance from settlements and roads", which will allow one to separate them from the most suitable biotopes.

Obtained geospatial information has reflected the behavioral features of the Eurasian lynx, which uses forest-meadow ecotones during hunting or during long-distance migration. On the territory of Transcarpathian region, a mountainous part is the most suitable for this indicator, as well as lowland forests located around the Chornyy Mochar tract and in the lower reaches of the Tisza, Borzhava and Latoritsa rivers.

An important factor is the altitude bioclimatic zones, which reflect the suitability of the local climate for the Eurasian lynx. We have defined these using SRTM data. The evaluation scores of high-altitude bioclimatic zones are presented in the Tab. 3. According to the methodology (Deodatus, Protsenko 2010, p. 61), the most suitable for lynx are bioclimatic altitudinal zones of moderately cool spruce-beech and cool beech-spruce forests, which are located in the altitude range from 700 to 1,300 m a.s.l. which are assigned 100 points. Zones of moderately warm beech forests (350–700 m a.s.l.) and very cool spruce forests (1,300–1,500 m a.s.l.) are also quite suitable (80 points) (Tab. 3).

It has been established that the area of suitable territories (with a score of 100 and 80 points) according to the specified parameter is 384.7 thousand hectares (30.2% of the territory of the Transcarpathian region). They are mainly distributed in the southeastern part of the Transcarpathian region, covering the

Tab. 3. Suitability of altitudinal bioclimatic zones for the Eurasian lynx

No.	High altitude bioclimatic zones	Altitudes (m a.s.l.)	Score (points)
1	Warm oak forests	0–350	50
2	Moderately warm beech forests	350–700	80
3	Moderately cool spruce-beech forests	700–1,100	100
4	Cool beech-spruce forests	1,100–1,300	100
5	Very cool spruce forests	1,300–1,500	80
6	Moderately cold subalpine	1,500–1,800	30
7	Cold alpine	Over 1,800	10

Source: Authors' own study.

northern slopes of the Maramoroskyy and southwestern slopes of the Chornohirskyy mountain ridges. In addition, upper parts of the slopes of the Polonynskyy and Vododilno-Verkhovynsky ridges are the most suitable. In the low mountains, the summit slopes of Vitrova Skala (1,025 m a.s.l.), Antalovetska Polyana (968 m a.s.l.), Makovytsia (978 m a.s.l.), Dunavka (1,018 m a.s.l.), Dehmaniv Verkh (1,018 m above the river level), Buzhora (1,081 m above the river level) of the Volcanic ridge are suitable.

SRTM data with a cell size of 30×30 m was also used to represent the raster layer, which reflects the suitability of landscapes with a certain degree of vertical relief fragmentation for the presence of lynx. Using the "relative heights and slope positions" tool, relative excess in meters were calculated based on these data, the suitability assessment of which is given in Tab. 4.

Tab. 4. Suitability of relative excesses for the habitat of the Eurasian lynx

No.	Relative excess (m)	Assessment
1	0–50	50
2	More than50	100

Source: Authors' own study.

It has been established that the highest rates of vertical dissection are typical for the mountainous part of the Transcarpathian region, namely for the Chornohirskyy, Maramoroskyy and Polonynskyy (up to the Latorytsia River) mountain ridges. The Vododilno-Verkhovynsky and Volcanic ridges, as well as the Polonynskyy ridge northwest of the Latorytsia River, are characterized by a somewhat lower level of dissection. The least suitable for this indicator is a flat part of Transcarpathian region.

To assess the suitability of the territory in terms of the "remoteness from settlements and roads" parameter, we used SRTM data with a cell size of 30×30 m and OpenStreetMap vector layers, which indicate railways, highways, main and secondary roads, as well as built-up areas. Based on the SRTM data within the study area, using the appropriate QGIS 3.16.8 raster analysis tool, the steepness of the slopes in degrees was calculated. Based on vector spatial data about railways, main, main and secondary roads, as well as built-up areas, we created a raster where the indicated objects correspond to the cell value 1, and 0 corresponds to all other territories. Using the "proximity (raster distance)" tool of the QGIS 3.16.8 software, the distance of any point within the study area from railways, main and secondary roads, as well as built-up areas in meters was determined. Based on the obtained rasters, using the tool "Raster Calculator" QGIS 3.16.8, a layer of distance from settlements and roads was calculated using the formula:

$$D = \left(\frac{\alpha}{5} + 1\right) \times L,$$

Where:
D – distance from settlements and roads
α – steepness of slopes (°)
L – distance from settlements and main roads (m)

The obtained values are scaled from 0 to 100, where 0 is roads and settlements, and 100 is the most remote areas from them. The resulting showed that the territories most remote from the anthropogenic factor are located in conditions of elevated dissected middle and low mountains on the border with Romania and Ivano-Frankivsk region, as well as along upper reaches of the Poloninskyy and Volcanic ridges. On the other hand, the leveled bottoms of the valleys of large and medium-sized rivers (Tisza, Teresva, Tereblya, Borzhava, Latorytsia, Rika, Uzha) and the Transcarpathian lowland are quite populated and, accordingly, unsuitable for the species.

For the purpose of an integral assessment of the suitability of biotopes for the presence of the Eurasian lynx, the resulting five-raster layers were combined using a weighted additive overlay analysis. As a result, we received a cartographic model, according to which it was established that the total area of territories potentially suitable for the presence of the Eurasian lynx within Transcarpathian region was 192.6 thousand hectares, and covers about 9.9% of the territory of the region. At the same time, the most suitable territories (with an integral assessment of more than 61 points) occupy 10.0 thousand hectares (0.2 and 9.8 thousand hectares, respectively).

The largest number of such habitats is concentrated in the mountainous southeastern part of the region within the elevated dissected middle highlands (index I in Fig. 1). This orographic ecoregion includes such morphogenic ecoregions as Inner Gorgany, Chornohora, Svydivets and Borzhava-Krasna, Rakhiv flysch and crystalline valleys (Kruhlov 2008). The most suitable biotopes formed as a result of modeling are also found within the boundaries of Gorganska Verkhovyna (at the border of Transcarpathian and Ivano-Frankivsk regions), which belongs to the orographic ecoregion elevated lowlands (index IV in Fig. 1) (Kruhlov 2008).

The analysis of information on the distribution of the Eurasian lynx ("Plan...") reflects a certain correlation between the obtained results of geoinformation modeling and the localities where the real presence of the species have been recorded (Bashta et al. 2004; Animalia database 2023). So, in addition to the elevated dissected middle mountains, isolated cases of fixing traces of the lynx habitation are also characteristic of the ecoregions of the middle mountains: within the Brdo-Manchula Valley (Polonyna), as well as the Ravka-Runa valley. One-time unconfirmed registrations are also typical for the Polonyna Bukovets ecoregion. It should be noted that traces of the presence of the species were also recorded in the conditions of elevated low mountains (Gorganska Verkhovyna ecoregion) on the border of the Transcarpathian and Ivano-Frankivsk regions.

In the conditions of low mountains, traces of the lynx presence were recorded by scientists in the ecoregion of the Vyhorlat-Hutynska ridge, as well as within the ecoregion of the Tsiroho-Ritskyy low mountains, which, according to our modeling, is characterized by a rather low level of habitability for the species.

According to the spatial data of the Global Biodiversity Information Fund (Animalia database 2023), the locations of the Eurasian lynx and other finds of traces of its life activity were registered mainly in the massifs of the Carpathian Biosphere Reserve, in the national natural parks "Uzhansky" and "Synevyr" where constant monitoring is carried out for the state of biotic diversity.

According to the methodology chosen by us, about 7 population plots with a total area of 175.9 thousand hectares, 6 reproductive ones (15.1 thousand hectares) and 575 others (1.6 thousand hectares). Among them, only 27.0% are within the nature protection area facilities and 33.5% are within the Emerald Network.

Reproductive and other habitats of Eurasian lynx are mostly located outside the protected areas. The largest areas in terms of population are located within the elevated dissected middle-land mountains. Within the middle-land mountains, population, reproduction and other, the areas are smaller.

It should also be noted that the local population of the Eurasian lynx can be replenished due to the migration of individuals from Romania and Poland, where, in addition to favorable conditions, there are also large nature protection areas.

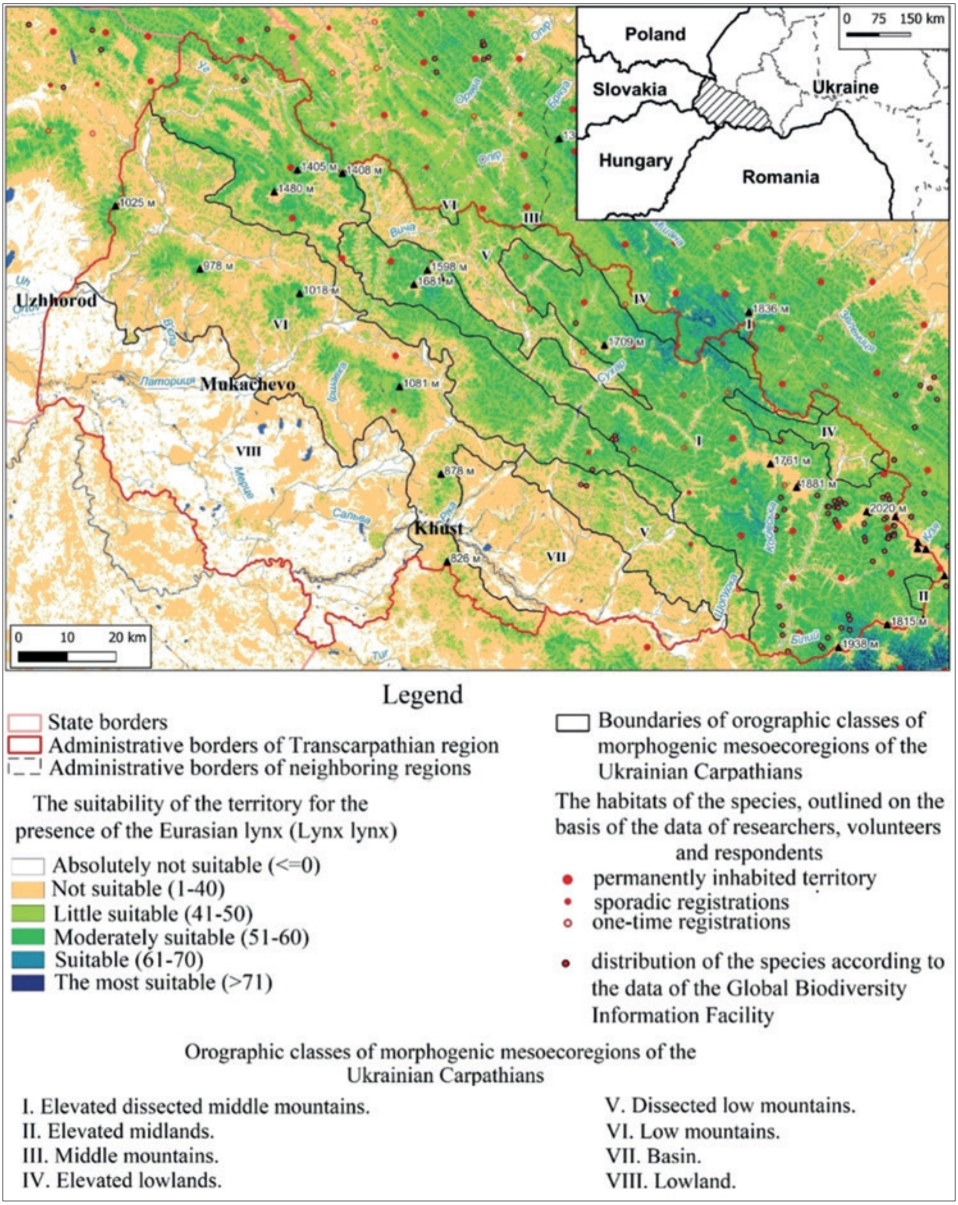

Fig. 1. Integral suitability of biotopes for the presence of the Eurasian lynx, recorded places of registration of the species (compiled according to Deodatus, Protsenko 2010; Kruhlov 2008; Bashta et al. 2004; Animalia database 2023)

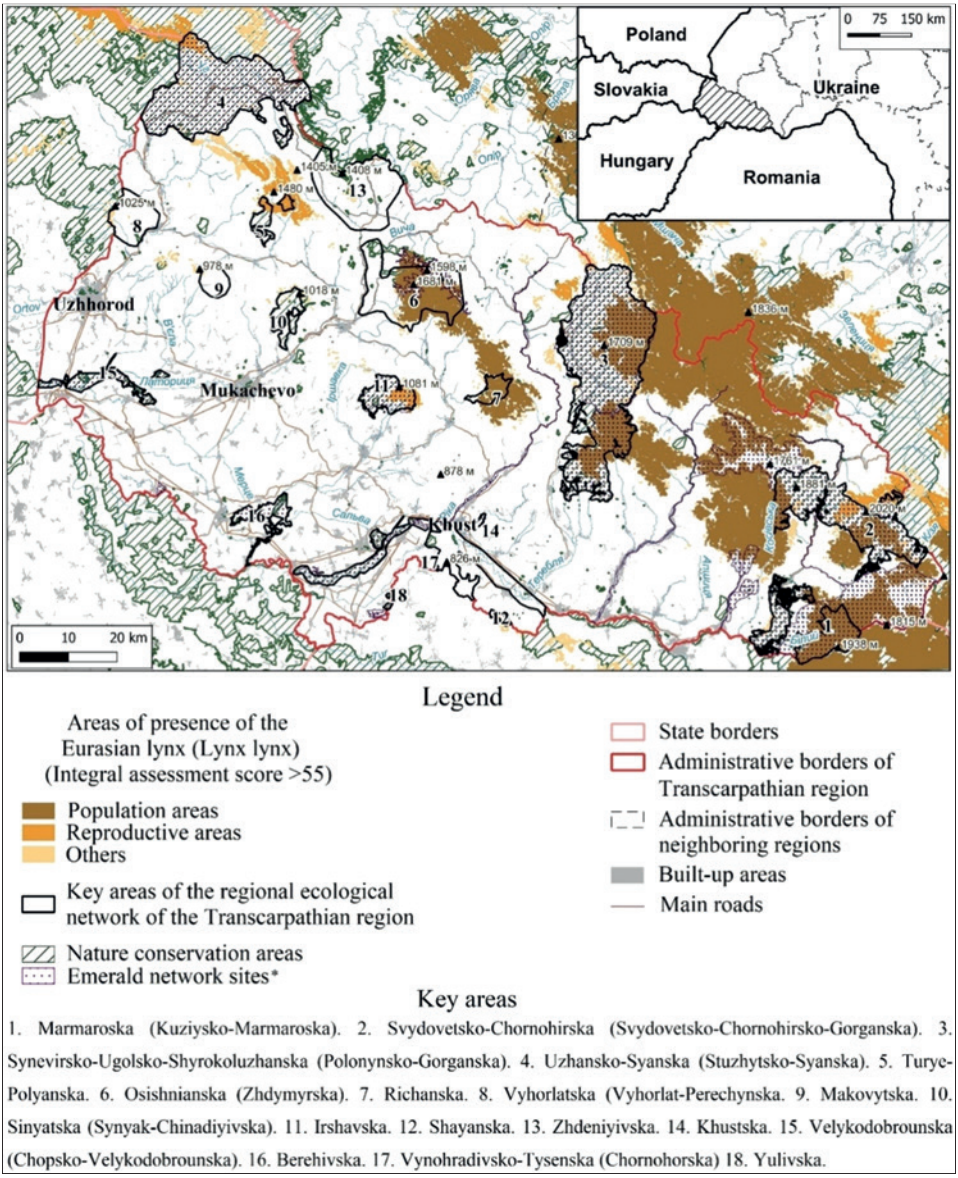

Fig. 2. Areas of potential presence of the Eurasian lynx and key areas of the regional ecological network of the Transcarpathian region (compiled according to Deodatus, Protsenko 2010; Brusak et al. 2006; Krychevska et al. 2010; Turys et al. 2015)

*Emerald network is an ecological network made up of Areas of Special Conservation Interest. Its implementation was launched by the Council of Europe as part of its work under the Bern Convention, with the adoption of Recommendation No. 16 (1989) of the Standing Committee to the Bern Convention (*Emerald Network of Areas of Special Conservation Interest*).

DISCUSSION

The first attempts to implement geo-informational modeling of Eurasian lynx habitats for the countries of the Carpathian region were carried out within the framework of the EU BioREGIO Carpathians project (BioREGIO WebGIS, database). The model was created using the ArcGIS geoinformation system by combining two spatial analysis tools: CorridorDesign and Linkage Mapper. Raster geoinformation data on land cover types (up to date as of 2006) and digital elevation model with a cell size of 100×100 m, as well as vector data on water bodies, settlements and roads were used for modeling. A similar technique formed the basis of the modeling of the Turkiv and Bukovyna ecological corridors in the Lviv and Chernivtsi regions in Ukraine (Deodatus, Protsenko 2010). The main methodological techniques and principles were adapted by us to the QGIS 3.16.8 software and used during the determination of important habitats for the presence of the Eurasian lynx in the Transcarpathian region. Since our model is based on high-resolution raster geospatial data on land cover and topography (the size of the raster cell is 30×30 m), as a result, we obtained more accurate boundaries of the areas where the species is located. This is also due to the high resolution of the original raster data. The high resolution allowed us to identify log cabins, individual buildings and other objects that fragment natural habitats. In addition, data on land cover are presented as of 2020. That is why the obtained result reflects the current level of suitability of the territory of the Transcarpathian region for the presence of the Eurasian lynx. It should be noted that the plots obtained by us cover a much smaller area compared to those modeled within the BioREGIO Carpathians project. In addition, according to the methodology (Deodatus, Protsenko 2010), depending on the minimum area, we separated population, reproduction and other areas.

The areas obtained in the process of geo-informational modeling, which are important for the presence of the European lynx (population, reproduction and others) in the Transcarpathian region, generally confirm the research results of zoologists (Bashta et al. 2004) that the distribution of the species is confined primarily to such mountain massifs of Transcarpathian region, such as the Marmarosy Mountains, Gorgany, Svydivets, Chornohora. The results of these studies will make it possible to establish migration routes, ecological corridors, the length of the daily course, the size of individual and brood areas, the habitat of the species, etc. This will give us the opportunity to determine the reliability of the results of our modeling, and if necessary, make changes to the methodology and adjust the boundaries of the delineated areas.

Research conducted by zoologists (Bashta et al. 2004) shows that the local population of the Eurasian lynx is declining. Further fragmentation of its natural habitats will lead to an even steeper decline. The Eurasian lynx is a species that is very sensitive to human presence. Zoologists also note that the species is better adapted to cooler conditions. Therefore, climate change and an increase in average annual temperatures could be another factor in the decline of the local population of Eurasian lynx. This calls for the conservation of the species' habitats. Part of the sites we have identified is under protection within the nature reserves and relevant key areas of the econetwork. At the same time, most of the selected areas are without appropriate protection. In our opinion, these territories are the basis for determining the boundaries of ecological corridors with the introduction of appropriate environmental measures and restrictions here. It is important to prevent poaching in these areas; restrict hunting for artiodactyls, which are the food base for the Eurasian lynx; to establish a system of control over the observance of the silence regime, especially during the breeding season of the species.

The implementation of the environmental protection regime, in particular through the creation of ecological corridors, will allow an increased level of control over compliance with environmental legislation. Such ecological corridors may become a limiting factor for the implementation of large-scale recreational projects in the Ukrainian Carpathians. Such projects involve the development of infrastructure that can significantly fragment natural habitats. Therefore, the introduction of a conservation regime here will contribute significantly to the conservation of the local population of the Eurasian lynx and biodiversity in general.

CONCLUSIONS

Our integral assessment, according to five parameters, of suitability of the biotopes of the Transcarpathian region for the presence of the Eurasian lynx showed that the total area of such biotopes is potentially 192.6 thousand hectares, and covers about 9.9% of the territory of the region. At the same time, the most suitable territories (with an integral assessment of more than 61 points) occupy 10.0 thousand hectares (0.2 and 9.8 thousand hectares, respectively). The largest number of such habitats is concentrated in the mountainous southeastern part of the region within the elevated, dissected middle highlands. Accordingly, the largest population areas of the Eurasian lynx are also concentrated in this morphogenic ecoregion. Population and reproduction areas within other morphogenic ecoregions of the region have been also modeled. In total, about 7 population plots with a total area of 175.9 thousand hectares, 6 reproduction plots (15.1 thousand hectares) and 575 others (1.6 thousand hectares) were modeled.

Today, only 27.0% of the territory of the sites established by us have a nature conservation status of national importance; about 33.5% of their area is part of the Emerald Network territories approved by the Standing Committee of the Bern Convention. A low level of protection can lead to further fragmentation of natural habitats due to the implementation of large projects in the energy and recreational sectors of the economy, development of road infrastructure, etc. In future, it is necessary to continue monitoring studies on the presence of the Eurasian lynx within the key territories of the Transcarpathian eco-network and more clearly delimit ecological corridors to implement measures to comply with environmental restrictions norms. The establishment of ecological corridors and the implementation of a conservation regime within them should include: implementation of a monitoring system for the Eurasian lynx population, increased control of compliance with environmental legislation, prevention of poaching and restrictions on clearcutting, etc. In addition, the creation of ecological corridors is a mechanism provided for by national legislation, but has not yet been applied in the Transcarpathian region. Delineation of the boundaries of ecological corridors is the first step towards the application of this mechanism.

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