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Landscapes connectivity in river Bregalnica watershed - determining the relative importance of rural landscapes for European wildcat conservation

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Abstract

Maintaining and enhancing habitat connectivity in semi-natural and cultural landscapes is essential for preserving biodiversity, ecosystem health, and the well-being of both wildlife and human communities. In this regard, this study aims to assess landscape connectivity across different landscape types in Bregalnica watershed, with a specific focus on evaluating the role of rural landscapes as corridors for the European wildcat (*Felis silvestris* Schreber, 1777).

Connectivity analysis was conducted in Graphab 2.8, using 50x50m rasterised habitat map as a baseline. A minimum patch size of 300 ha was applied to define habitat nodes, and a 1,500 m dispersal threshold was used for species movement through unsuitable habitats.

Forest landscapes within the Bregalnica watershed were found to have the highest cumulative core patch value. Rural landscapes–while secondary to forests–also provide habitat for the wildcat and play a significant role in supporting habitat connectivity for the species. Three rural landscape types support European wildcat populations by providing suitable habitat and enabling connectivity between populations: Hilly rural landscape, Mountain rural landscape and Osogovo mountain rural landscape. Among these, the latter is the most critical for core area presence and connectivity. The Hilly rural landscape is the most valuable in terms of corridor presence.

The outputs of this study contribute towards wildlife conservation efforts and the integrated management of ecological networks in the Bregalnica watershed region.

Keywords: corridor, wildlife conservation, landscape management

Introduction

Natural habitat connectivity plays an important role in maintaining biodiversity and ecosystem health within semi-natural and cultural landscapes (Correa Ayram et al. 2016; Velázquez et al. 2019), where human activities have notably altered the natural environment (Baguette et al. 2013; Grass et al. 2019). Amidst the socio-environmental changes brought about by modern life, maintaining and improving habitat connectivity is essential for the well-being of both wildlife and human communities (Auffret et al. 2015; Kang et al. 2015).

Habitat connectivity is vital for enhancing the resilience of conservation-dependent species, particularly large mammals (Bailey 2007; Taylor et al. 1993; Correa Ayram et al. 2016). It determines the likelihood of a given organism moving between habitat patches, considering the nature of the intervening environment and the organism's dispersal capability (Tischendorf and Fahrig 2000). Hence, it allows conservationists to identify potential corridors and provides insights into the probability of target species moving through these corridors (Correa Ayram et al. 2016; Watts et al. 2010). Landscapes with high connectivity also have greater potential for providing ecosystem services (Mitchell et al. 2013), especially regulatory and provisioning services, and are more resilient to natural disturbances (Thrush et al. 2013).

Given that the long lasting extensive human impact on the environment has played a significant role in shaping the highly diverse array of natural ecosystems

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in North Macedonia, a high diversity of landscapes is apparent (Melovski et al. 2019). The human contribution in determination of the landscape character is most evident in agricultural and rural landscapes (Brady 2006; Špulerová and Petrovič 2012; Melovski et al. 2019). This long-lasting human-nature interaction has had a distinctive role in nurturing secondary anthropogenic habitats (Harvey et al. 2008; Cevasco and Moreno 2013) which are significant for the preservation of biodiversity (Pimentel et al. 1992; Thies 1999; Atauri and De Lucio 2001; Falcucci et al. 2006). The assessment of connectivity offers valuable guidelines for land-use planning. It allows for the identification of habitat patches where active management measures should be implemented. Furthermore, it lays the foundation for developing policies aimed at conserving biological diversity and ecosystems. Connectivity assessment is crucial for preservation of the landscape functionality (Turner 1989; Kupfer 2012), especially in a region where there are ongoing conservational efforts (Kheirkhah Ghehi et al. 2020).

River Bregalnica watershed has high potential for biodiversity conservation, while significant portion of the watershed is represented by agricultural and rural landscapes (Jovanovska et al. 2017; Melovski et al. 2019). Habitat connectivity assessment can provide arguments to inform land-use planning and land management and support biodiversity conservation (Scolozzi and Geneletti 2012) while continuing to support human well-being.

This study contributes to wildlife conservation efforts by focusing on the European wildcat (*Felis silvestris* Schreber, 1775)—a small feline found across Europe, Scotland, Turkey, and the Caucasus—as a key species for evaluating the importance of different landscape types in linking resource patches and sustaining wildlife. Despite this extensive range, wildcat's distribution is highly fragmented on both regional and local levels (Gil-Sánchez et al. 2020), leading to isolated populations that are at significant risk of extinction (Lozano and Malo 2012). Its global population is now in decline, although it's globally listed as Near Threatened by the International Union for Conservation of Nature (Gerngross et al. 2023). In North Macedonia the species is protected by the national Law on Game Hunting (Official Gazette of RNM 263/2023). The species is also protected under several EU legal protection frameworks (Annex IV of the EU Habitats Directive 92/43/EEC) and international conservation instruments: Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora, CITES 1973) and Appendix II of the Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats, Council of Europe, 1979). Main threats involve road collisions and hybridization with the domestic cat (Urzi et al. 2021) and possibly fragmentation. Hence, preserving the long-term survival of the wildcat hinges upon maintaining habitat connectivity in environments that have become fragmented (Gil-Sánchez et al. 2020).

Identifying and prioritizing corridors marks the initial phase in preserving and restoring habitat connectivity in fragmented landscapes. This is essential for ensuring the population viability of the European wildcat impacted by local isolation and loss of functional connectivity (Hartmann et al. 2013), and should be integrated into the design and execution of effective conservation initiatives. To enhance conservation efforts for the Eu-

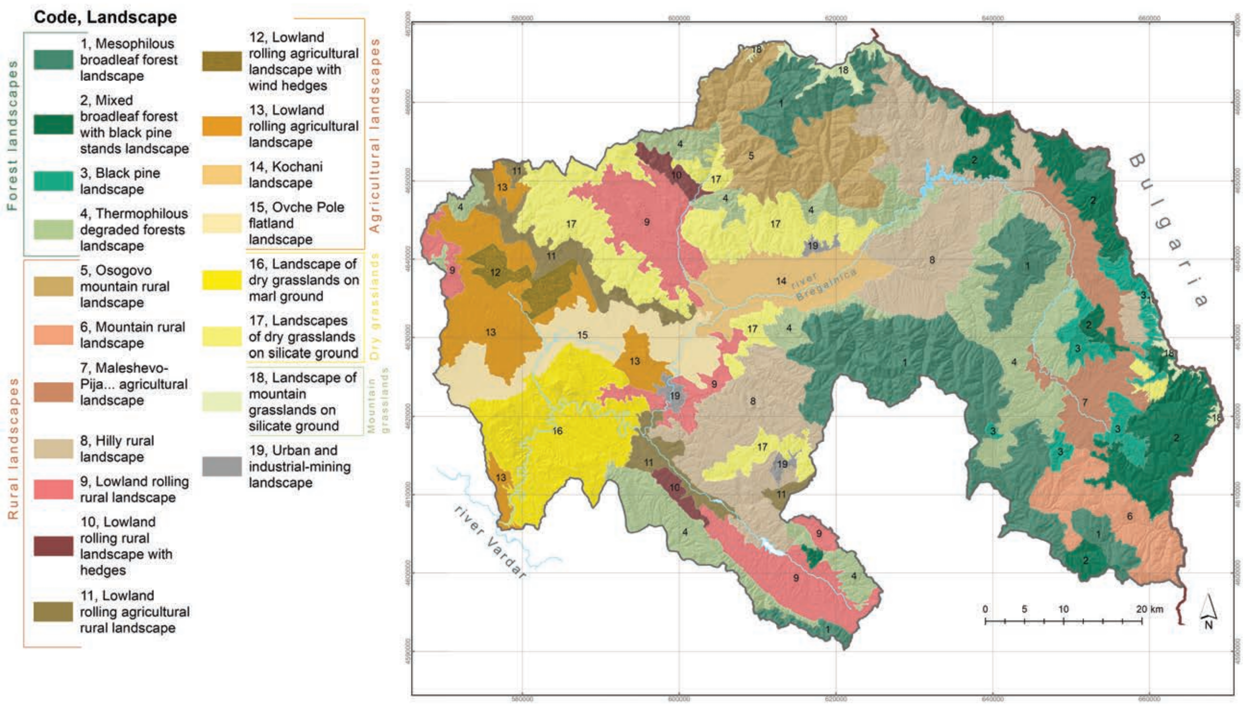

Fig 1. Landscapes diversity in the river Bregalnica watershed

Table 1. Characterization matrix for landscapes in Bregalnica watershed. Modified from Melovski et al. (2015)

	Relief (inclination exposition)	Potential vegetation (Land cover)	Geology and soils	Land use	Climate	Naturalness	Settlements and cultural characteristics	History	Landscape type	Landscape group
1. Low-lands, to 400 m	Flatland	Lacking or narrow corridors of flooding forests	Alluvium; Clay soils	Intensive–rice fields	Sub-mediterranean influence	Mainly artificial	Dispersed, not dense, of compact type	Continuous use	Kochani landscape	Agricultural landscapes
			Alluvium or marl; saline soils	Intensive - crops					Ovche Pole flatland landscape	
2. Foots, to 600 m	Rolling; mild slopes	Lacking	Alluvium or marl; saline soils	Intensive - crops	Sub-mediterranean influence to warm continental	Mainly artificial	Dispersed, not dense, of compact type	Continuous use	Lowland rolling agricultural landscape	
								Continuous use with anthropogenic manipulation	Lowland rolling agricultural landscape with wind hedges	
		Almost lacking	Alluvium or marl; terraces	Moderately intensive, diverse crops				Continuous use, signs of abandonment	Lowland rolling agricultural rural landscape	Rural landscapes
		Small remains of oak woodlands		Extensive agriculture		Strongly altered	Rather dense villages of compact type; small plots	Slight signs of abandonment	Lowland rolling rural landscape	
							Dense villages of compact type; small plots with hedge-rows		Lowland rolling rural landscape with hedges	
3. Low elevation belt (600-900-1000 m)	Flatland	Lacking	Sediments and deposits - silicate	Relatively intensive agriculture	Warm continental to continental	Mainly artificial	Villages of compact type and towns	Continuous use	Maleshevo-Pijanec rural agricultural landscape	
	Hilly; steep and mild slopes, deep dales	Remains of oak woodlands	Silicate ground	Extensive agriculture	Warm continental with weak mediter-ranen influence	Strongly altered	Rather dense villages of compact type; small plots	Slight signs of abandonment	Hilly rural landscape	
		Small remains of oak woodlands; shrubby stands		Livestock breeding		Semi-natural	Sparse villages of compact type	Abandonment	Landscape of dry grasslands on silicate ground	Dry grasslands landscapes
			Marl ground				Very sparse villages of compact type, abandoned		Landscape of dry grasslands on marl ground	
4. Medium elevation belt (700-900-1400 m)	Hilly-mountain; and mild slopes, deep dales	Xero-thermophilous degraded oak forests	Silicate ground	Forestry	Warm continental		No settlements	Abandonment of use	Thermophilous degraded forests landscape	Forest landscapes
		Thermophilous and mesophilous oak forests; pine plantations		Forestry		Mainly artificial forests	No or very rare settlements	Active management and use	Mixed broadleaf forest with black pine stands landscape	
		Thermophilous oak and mesophilous oak and beech forests		Very extensive agriculture, forestry		Altered forests - sparse	Dispersed – of broken type, high number of neighbourhoods	Abandonment	Osogovo mountain rural landscape	Rural landscapes
							Distinctive organization of huts, typical settlements absent	Large areas of extensive agriculture	Mountain rural landscape	
5. High moun-tain belt (1400-1800 m)	Mountain; and mild slopes, deep dales	Beech and sessile oak forests	Silicate ground	Forestry	Continental to mountain	Semi-natural to natural	Lacking	Continuous use	Mesophilous broadleaf forest landscape	Forest landscapes
		Black pine, white pine and mixed forests							Pine forest landscape	
6. Sub-alpine and alpine zone (>1800 m)	Mountain; mainly mild slopes and shallow dales	Subalpine pastures, heaths, peat bogs	Silicate ground	Livestock breeding, berry collection	Mountain	Semi-natural to natural	No settlements; rare sheepfolds	Continuous use with signs of abandonment	Landscape of mountain grasslands on silicate ground	Mountain grasslands landscape

*Urban and industrial-mining landscapes have been omitted ropean wildcat, this study aims to provide a framework for identifying and prioritizing such corridors within a mosaic of semi-natural and cultural landscapes.

Methodology

Study area

River Bregalnica watershed occupies a territory of 4302.6 km^2 in the eastern part of North Macedonia. The geomorphological and habitat diversity of the river Bregalnica watershed (Hristovski and Brajanoska 2015) alongside the long-standing and varied human activities has resulted in high landscape diversity (Figure 1). The watershed encompasses as many as twenty distinct landscape types, which differ in character due to environmental variations, differences in vegetation cover and history of land use (Melovski et al. 2015, 2019). Landscape specifics are provided in Table 1.

Connectivity assessment

Given its conservation importance, and taking into account the availability of data regarding species presence, the European wildcat was chosen as a focal species to assess the significance of rural landscapes as both core areas and corridors for its movement.

Data preparation, data processing and mapping were carried in ArcGIS 10.2 software (ESRI 2013). Landscape connectivity analysis was assessed using Graphab 2.8 software (Foltête et al. 2012, 2021). The assessment was carried using custom-modified land cover layer based on CLC 2018 (EEA 2018), enhanced through digitization to delineate finer landscape elements with greater spatial accuracy than the original dataset allows. The modified vector data was then rasterized to 50x50 meters resolution to produce a habitat map for the defined area of interest - the river Bregalnica watershed.

All land cover types were then graded for their suitability to sustain breeding populations of the wildcat based on available literature data (Monterroso et al. 2009; Klar et al. 2008; Gil-Sánchez et al. 2020) and expert knowledge for species habitat requirements, habitat permeability, and prey availability (Table 2).

For the purpose of the assessment, land cover classes were assigned weighting factors with values ranging [0 - 100] (where 0 indicates the core areas, and 100 - most unfavorable habitat types), representing the accumulative resistance cost of species movement through each raster cell to the nearest habitat patch.

Table 2. Applied weighting factors.

CLC code	CLC description	Weighting factor	Rationale considering region specifics
311	Broad-leaved forest	0	Core habitat providing excellent cover, denning sites, and high prey availability. Highest suitability and permeability.
312	Coniferous forest	0	
313	Mixed forest	0	
244	Agro-forestry areas	20	Provide moderate shelter and hunting opportunities; permeability varies, with lower suitability than forest but still usable habitat or corridors.
324	Transitional woodland-shrub	20	
243	Land principally occupied by agriculture, with significant areas of natural vegetation	30	
221	Vineyards	40	Offer limited prey and partial cover. Used mainly for movement or occasional foraging; moderate to low suitability
222	Fruit trees and berry plantations	40	
321	Natural grasslands	40	Provide moderate shelter and hunting opportunities and can function as corridors, but their lack of vertical structure, high exposure, and limited refuge potential result in lower permeability and habitat quality compared to wooded transitional zones.
231	Pastures	50	
323	Sclerophyllous vegetation	50	
333	Sparsely vegetated areas	60	Limited vegetation, poor prey availability. Avoided unless near more suitable habitat
242	Complex cultivation patterns	70	Low structural complexity and poor cover. Poor prey availability; high disturbance, avoided unless near better habitat. Low permeability
211	Non-irrigated arable land	80	
213	Rice fields	80	
331	Beaches, dunes, sands	90	Limited vegetation, poor suitability; Avoided unless near more suitable habitat
112	Discontinuous urban fabric	95	Represent high human disturbance, physical barriers, and lack of prey. Very poor suitability and largely avoided.
121	Industrial or commercial units	95	
131	Mineral extraction sites	95	
132	Dump sites	95	
133	Construction sites	95	
512	Water bodies	100	Absolute barriers for wildcat movement; no suitability

The habitat connectivity analyzes were performed using 50x50m rasterized habitat map. Habitat patches were defined using 8-neighbour connectivity (con8=true), with a minimum patch area of 300 ha (minArea=3,000,000 m²). Connectivity graphs were constructed using least-cost paths, considering a maximum dispersal distance of 1,500 meters (distMax=1500), and paths crossing the same patch were removed (removeCrossPatch=true). The linkset used Euclidean distances weighted by cost, and intra-patch distances were included (intraPatchDist=true).

Functional connectivity was assessed using 'delta Probability of Connectivity', assessing the relative importance of each element (patch node/corridor link) by computing the rate of variation in the global metric induced by each addition/removal [resulting value 0-1]. Links were saved as paths representing the actual route of the link between two patches identifying and delineating potential roots or pathways between different habitat patches.

ArcGIS was used for zonal analyses, to quantify the contribution of habitat patches and corridors to overall landscape connectivity within defined spatial units (landscapes and landscape groups). The connectivity performance of both patches and corridors across different landscape types was then calculated using the following equations:

To estimate how much each patch within landscape x contributes to connectivity:

$$PVxy = AREA(PATCHxy)*dPC(PATCHy); \Sigma PVx = PVx1+PVx2+\ldots+PVxn$$

where:

"x" - landscape or landscape group number; "PATCHy" - core patch "y"; "AREA(PATCHxy)" - area of the segment of "PATCHy" inside landscape "x"; "dPC" - delta connectivity of probability value; "PVxy" - Patch segment connectivity value; "ΣPVx" - cumulative connectivity value of all core patch segments in landscape "x"

To measure the connectivity value contributed by corridor segments crossing landscape x:

$$CVxz = LENGTH\ (CORRIDORxz) * dPC\ (CORRIDORz)*REAL\_DIST(CORRIDORz) / COST\_DIST\ (CORRIDORz); \Sigma CVx = CVx1+CVx2+\ldots+CVxn$$

where:

"x" - landscape or landscape group number; "CORRIDORz" - corridor "z"; "LENGTH(CORRIDORxz)" - length of the segment of "CORRIDORz" inside landscape "x"; "dPC" - delta connectivity of probability value; "REAL_DIST(CORRIDORz)" - real distance of "CORRIDORz"; "COST_DIST(CORRIDORz)" - weighted distance of "CORRIDORz"; "CVxz" - Corridor segment connectivity value; "Σ CVx" - cumulative connectivity value of all corridor segments in landscape "x".

To ensure comparability between landscapes of differing size:

$$\Sigma CVnormalized = 100*(\Sigma CVx - MIN\Sigma CV) / MAX(\Sigma CV)-MIN(\Sigma CV)$$

where:

MAX(ΣPV) - Highest cumulative patch connectivity value of all landscapes/landscape groups; MAX(ΣCV) - Highest cumulative corridor connectivity value of all landscapes/landscape groups;

The connectivity assessment of landscape groups was carried by summing the connectivity scores for the individual landscape types within landscape groups.

Camera traps were used to provide data on wildcat presence or absence relative to the connectivity model output. Information was obtained from 18 infrared camera-traps (models Scoutguard® and Keep Guard®) deployed at 18 locations (see Fig. 3). The cameras operated during three separate periods: from 16 December 2014 to 07 April 2015 at 4 locations, from 11 February to 08 April 2015 at another 4 locations, from 16 June to 15 July 2015 at 4 locations and from 12 August to 15 September 2015 at 6 locations.

Results

Forest landscapes in Bregalnica watershed were assessed to have the highest cumulative (landscape group) core patch value (Table 3). Within them, the Mesophilous broadleaf forest landscapes on Osogovo and Plachkovica (Melovski et al. 2013, 2015) feature the largest continuous areas of suitable habitat patches. Rural landscapes were also found to have relatively high cumulative core patch value (26.17), with the Osogovo Mountain rural landscape (16.05) approaching the value of the Thermophilous degraded forest landscape (16.27). The cumulative patch value of the Mountain rural landscape (12.37) was also assessed as relatively high, greater than the cumulative patch value of the Mixed broadleaf forest with black pine stands (8.59). The highest cumulative (landscape group) corridor value was observed in Forest landscapes (100), followed by Rural landscapes (16.01). The Thermophillous degraded forest landscape was assessed to have highest cumulative corridor value (100), with significant cumulative corridor values also observed in the Mesophilous forest landscape (23.11) and the Hilly rural landscape (19.79).

Wildcat's core area and corridor presence and importance in river Bregalnica watershed are presented on Figure 2 and Figure 3.

The cumulative patch value (ΣPV) and cumulative corridor value (ΣCV) outline the relative importance of

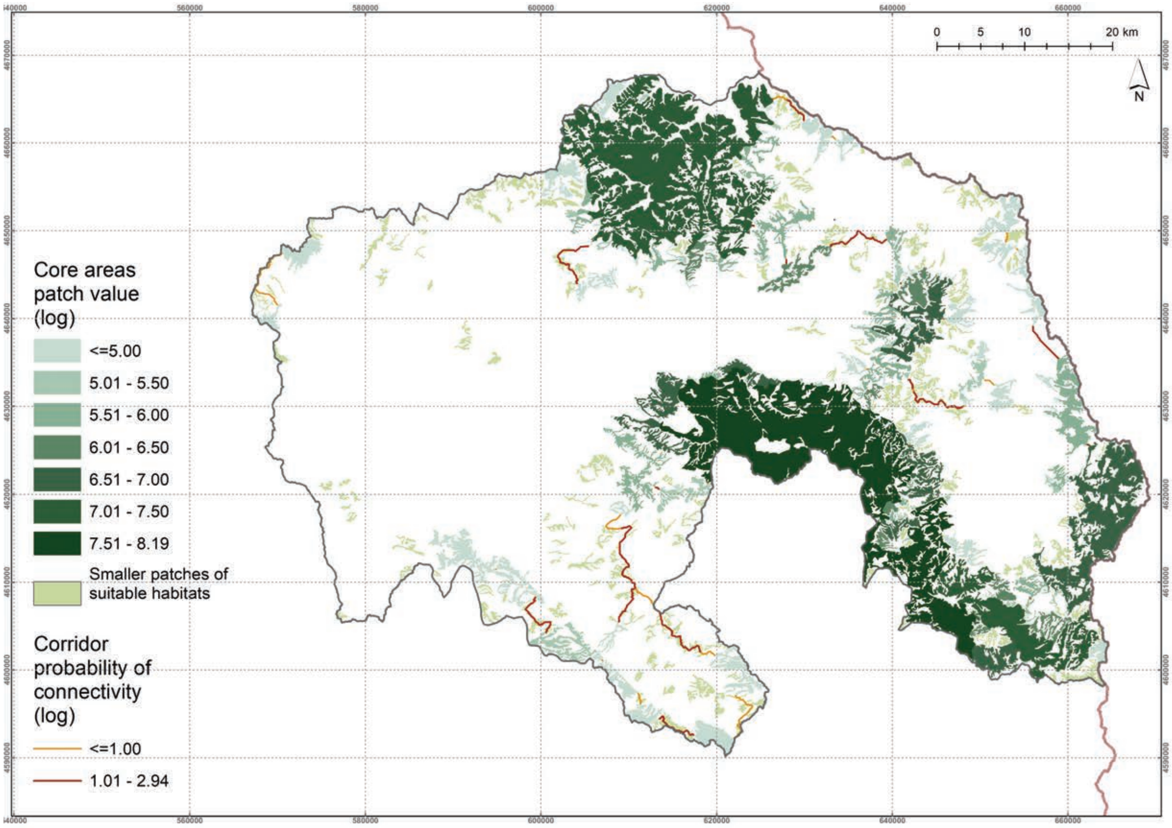

Fig. 2. Wildcat's core area and corridor presence and importance in the Bregalnica watershed.

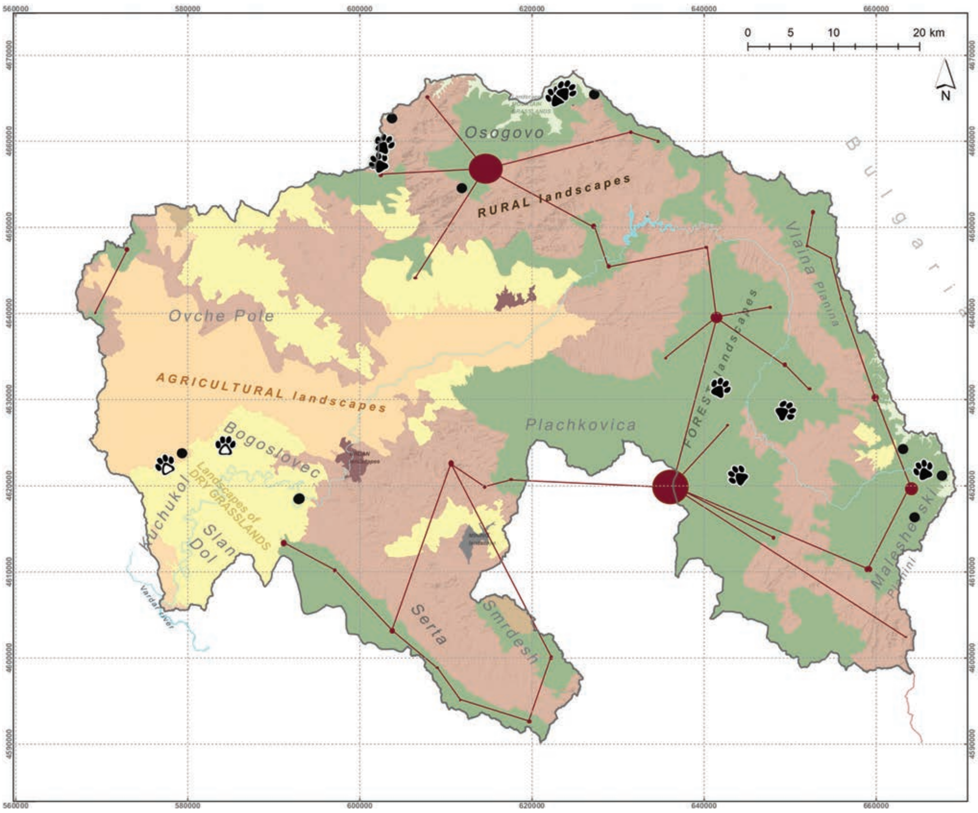

Fig. 3. Schematic representation of core area and connectivity assessment in river Bregalnica watershed. Paws indicate camera-traps data with confirmed wildcat presence – fully colored indicating viable European wildcat populations and partially colored indicate observed hybridization. Black dots indicate camera-traps locations where wildcat presence was not confirmed.

Table 3. Cumulative corridor and suitable habitat patch value of landscapes in river Bregalnica watershed

Landscape group /Landscape type	Patch Value (ΣPV)*	Corridor Value (ΣCV)*	Log ΣPV+ΣCV**
Forest landscapes	**100**	**100**	**8.83**
Mesophilous broadleaf forest landscape	100	23.11	8.52
Thermophilous degraded forests landscape	16.27	100.00	8.49
Mixed broadleaf forest with black pine stands landscape	8.59	2.90	7.49
Black pine landscape	1.10	3.74	7.11
Rural landscapes	**26.17**	**16.01**	**8.15**
Osogovo mountain rural landscape	16.05	0.47	7.64
Mountain rural landscape	12.37	0.08	7.52
Hilly rural landscape	4.34	19.79	7.81
Maleshevo-Pijanec rural-agricultural landscape	0.19	0.00	5.71
Lowland rolling rural landscape	0.01	0.30	5.92
Lowland rolling rural landscape with hedges	0.00	0.00	3.15
Lowland rolling agricultural-rural landscape	0	0.13	5.55
Agricultural landscapes	**0.02**	**0.00**	**4.86**
Lowland rolling agricultural landscape	0	0	0
Lowland rolling agricultural landscape with wind hedges	0	0	0
Kochani landscape	0.03	0.00	4.86
Ovche Pole flatland landscape	0	0	0
Dry grasslands landscapes	**0.80**	**3.14**	**7.12**
Landscapes of dry grasslands on silicate ground	0.98	4.07	7.13
Landscape of dry grasslands on marl ground	0.02	0.00	4.75
Mountain grasslands landscapes	**0.15**	**0.40**	**6.16**
Landscape of mountain grasslands on silicate ground	0.15	0.40	6.16

*ΣPV and ΣCV normalized from maximum recorded patch value %

**Log10 (ΣPV + ΣCV normalized to PV)

different landscape types in fostering habitat continuity and supporting wildlife. While forest landscapes had the highest cumulative core patch connectivity value, the assessment also highlighted the important role of rural landscapes in supporting the connectivity of core habitat patches. When rural landscapes are evaluated individually for their significance in supporting the wildcat, the Osogovo Mountain rural landscape stands out with the highest cumulative patch value (79.95) and corridor value (57.26). This indicates its potential to function as a core area for the wildcat. Additionally, the Mountain rural landscape has a relatively high cumulative patch area (47.94), though its cumulative corridor area is significantly lower (3.95). Similarly, the Hilly rural landscape also plays an important role in supporting the wildcat population in Bregalnica watershed with a cumulative patch value of 36.69 and a corridor value of 22.53. Within this landscape, the Plachkovica Mountain unit has the highest patch value of 15.75 and a corridor value of 14.56.

Data obtained from camera-trap surveys go in line with the connectivity assessment outputs and indicate presence of viable European wildcat populations in the northern, western, and southwestern regions of the river Bregalnica watershed (Figure 3). However, the limited number and duration of surveys are not sufficient to validate or calibrate the model, highlighting the need for more extensive field data.

Discussion

Forest landscapes emerged as core habitat areas with the highest connectivity value for the European wildcat, outlining their role in supporting stable populations. However, the results also highlight the role of rural landscapes in providing habitat and facilitating movement for this species. The study also reveals that within a single landscape type, different landscape units can vary in their cumulative corridor and patch values. This suggests that not all areas within a particular landscape type contribute equally to landscape connectivity, and for maintaining wildlife corridors and habitats the preservation and active management of some areas may be more crucial than others.

Specifically, the connectivity model outlines three rural landscapes–the Osogovo mountain rural landscape, the Mountain rural landscape, and the Hilly rural landscape–as crucial in promoting connectivity within the river Bregalnica watershed. This aligns with the camera-trap data confirming viable populations of wild cat in this area. Conversely, the connectivity assessment outlines the limited connectivity of the landscapes of dry grasslands, the agricultural and the rural landscapes in the regions of Serta, Smrdesh, Slan Dol, Kuchukol, and Ovche Pole. This aligns with camera-trap data indicating that individuals recorded in these areas exhibit hybridization, suggesting introgression with domestic cats.

However, the limited number of camera traps and the short duration of the survey do not allow for a full validation of the connectivity model. Additional, long-term monitoring using a broader network of camera traps would be necessary to confirm these patterns and better understand population dynamics and connectivity in these areas. While connectivity models are indicative rather than absolute representations of movement and habitat use, they remain a critical tool for conservation planning (Zeller et al. 2012). Despite their limitations in precision, such models help identify and prioritize key habitat corridors, marking the initial and essential phase in preserving and restoring landscape connectivity (Bailey 2007; Taylor et al. 1993; Correa Ayram et al. 2016).

Identifying and prioritizing corridors is an important step in maintaining and enhancing habitat connectivity (Bailey 2007; Taylor et al. 1993; Correa Ayram et al. 2016), forming the backbone of effective conservation initiatives. Conservation efforts should focus on maintaining and restoring functional corridors between core habitats (Correa Ayram et al. 2016; Hartmann et al. 2013), mitigating human disturbances (Piñeiro et al. 2012; Ruiz-Villar et al. 2024), and managing prey populations (Malo et al. 2004) to sustain wildcat populations in the long term. This broader ecological strategy ensures that populations are not confined to isolated patches, thereby reducing their vulnerability and increasing genetic resilience to environmental change (Lozano and Malo 2012).

In this regard, the recent establishment of the Osogovo Mountains protected area (Official Gazette 277/2020 of 20.11.2020) and the management actions focused on its most prominent attribute, the Osogovo mountain rural landscape ensure the preservation of existing natural habitats and corridors. Additionally, the designation of the Maleshevo protected area (Official Gazette 162/2021 of 16.07.2021) further strengthens conservation management practices in the Mixed broadleaf forest landscape with black pine stands, maintaining its significance as a core area and corridor. Extending these effective management practices across the river Bregalnica watershed can enhance the value of the Rolling rural landscape and the Rolling rural landscape with hedges as wildcat corridors, thereby increasing wildcat population viability in the western and southwestern parts of the watershed. European wildcat conservation efforts in the Bregalnica watershed and similar landscapes hinge on proactive management and a holistic approach to landscape conservation.

The disparity in connectivity between the Forest landscapes, the Osogovo mountain rural landscape, the Mountain rural landscape and the Hilly rural landscape compared to Agricultural landscapes and other rural landscape types where human alterations are more intensive, highlights the need for targeted conservation strategies in the river Bregalnica watershed. Preserving and managing these transitional zones is essential for balancing human needs with conservation goals (Kang et al. 2015; Auffret et al. 2015), fostering a harmonious coexistence between human development and natural ecosystems.

This is particularly important for ensuring the long-term viability of European wildcat populations, which are increasingly affected by local isolation and the loss of functional connectivity (Hartmann et al. 2013). As such, outputs from connectivity models should be integrated into the design and implementation of targeted and effective conservation measures (Portanier et al. 2022).

Conclusions

Considering all landscape groups in the Bregalnica watershed, the Rural landscapes group ranks second in both core area and corridor presence and importance, following the Forest landscapes group, which is recognized as the primary core area for the wildcat. Among rural landscape types, only three provide sufficient habitat to function as core areas for wildcat populations: Hilly rural landscape, Osogovo mountain rural landscape, and Mountain rural landscape. Of these, the Osogovo mountain rural landscape plays the most critical role in terms of core area presence and importance for connectivity. Additionally, within the rural landscapes, the Hilly rural landscape holds the highest value for both corridor presence and corridor importance.

These findings underline the effectiveness of existing habitat corridors in river Bregalnica watershed, facilitating movement and genetic exchange among wildcat populations, which is crucial for their long-term viability. To sustain and enhance these functions, outputs from connectivity models should be integrated into the design and implementation of targeted and effective conservation measures.

References

Atauri, J. A., De Lucio, J. V. (2001). The role of landscape structure in species richness distribution of birds, amphibians, reptiles and lepidopterans in Mediterranean landscapes. *Landscape ecology* **16**(2): 147–159.

Auffret, A. G., Plue, J., Cousins, S. A. O. (2015). The spatial and temporal components of functional connectivity in fragmented landscapes. *AMBIO* **44**(1): 51–59.

Baguette, M., Blanchet, S., Legrand, D., Stevens, V. M., Turlure, C. (2013). Individual dispersal, landscape connectivity and ecological networks. *Biological Reviews* **88**(2): 310–326.

Bailey, S. (2007). Increasing connectivity in fragmented landscapes: An investigation of evidence for biodiversity gain in woodlands. *Forest Ecology and Management* **238**(1): 7–23.

Brady, E. (2006). The Aesthetics of Agricultural Landscapes and the Relationship between Humans and Nature. *Ethics, Place & Environment* **9**(1): 1–19.

Cevasco, R., Moreno, D. (2013). Rural Landscapes: The Historical Roots of Biodiversity. In: Agnoletti, M. (ed.). *Italian Historical Rural Landscapes* pp. 141–152. Springer Netherlands, Dordrecht.

Correa Ayram, C. A., Mendoza, M. E., Etter, A., Salicrup, D. R. P. (2016). Habitat connectivity in biodiversity conservation: A review of recent studies and applications. *Progress in Physical Geography: Earth and Environment* **40**(1): 7–37.

Falcucci, A., Maiorano, L., Boitani, L. (2006). Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. *Landscape Ecology* **22**(4): 617–631.

Foltête, J.-C., Clauzel, C., Vuidel, G. (2012). A software tool dedicated to the modelling of landscape networks. *Environmental Modelling & Software* **38**: 316–327.

Foltête, J.-C., Vuidel, G., Savary, P., Clauzel, C., Sahraoui, Y., Girardet, X., Bourgeois, M. (2021). Graphab: An application for modeling and managing ecological habitat networks. *Software Impacts* **8**: 100065.

Gerngross, P., Ambarli, H., Angelici, F. M., Anile, S., Campbell, R., Ferreras de Andres, P., Gil-Sanchez, J. M., Götz, M., Jerosch, S., Mengüllüoglu, D., Monterroso, P., Zlatanova, D. (2023). Felis silvestris (amended version of 2022 assessment). The IUCN Red List of Threatened Species 2023: e.T181049859A224982454. doi: 10.2305/IUCN.UK.2023-1.RLTS.T181049859A224982454.en.

Gil-Sánchez, J. M., Barea-Azcón, J. M., Jaramillo, J., Herrera-Sánchez, F. J., Jiménez, J., Virgós, E. (2020). Fragmentation and low density as major conservation challenges for the southernmost populations of the European wildcat. *PLOS ONE* **15**(1): e0227708.

Grass, I., Loos, J., Baensch, S., Batáry, P., Librán-Embid, F., Ficiciyan, A., Klaus, F., Riechers, M., Rosa, J., Tiede, J., Udy, K., Westphal, C., Wurz, A., Tscharntke, T. (2019). Land-sharing/-sparing connectivity landscapes for ecosystem services and biodiversity conservation. *People and Nature* **1**(2): 262–272.

Hartmann, S. A., Steyer, K., Kraus, R. H. S., Segelbacher, G., Nowak, C. (2013). Potential barriers to gene flow in the endangered European wildcat (Felis silvestris). *Conservation Genetics* **14**(2): 413–426.

Harvey, C. A., Komar, O., Chazdon, R., Ferguson, B. G., Finegan, B., Griffith, D. M., MartíNez-Ramos, M., Morales, H., Nigh, R., Soto-Pinto, L., Van Breugel, M., Wishnie, M. (2008). Integrating Agricultural Landscapes with Biodiversity Conservation in the Mesoamerican Hotspot. *Conservation Biology* **22**(1): 8–15.

Hristovski, S., Brajanoska, R. (eds.). (2015). *Biodiversity of the Bregalnica River Watershed. Final project report "Ecological Data Gap Analysis and Ecological Sensitivity Map Development for the Bregalnica River Watershed"*. Book 2. Skopje, 127 p.

Jovanovska, D., Avukatov, V., Melovski, L. (2017). Structural properties of agricultural and rural landscapes in river Bregalnica watershed. *Macedonian Journal of Ecology and Environment* **19**(1): 5–14.

Kang, W., Minor, E. S., Park, C.-R., Lee, D. (2015). Effects of habitat structure, human disturbance, and habitat connectivity on urban forest bird communities. *Urban Ecosystems* **18**(3): 857–870.

Kheirkhah Ghehi, N., MalekMohammadi, B., Jafari, H. (2020). Integrating habitat risk assessment and connectivity analysis in ranking habitat patches for conservation in protected areas. *Journal for Nature Conservation* **56**: 125867.

Klar, N., Fernández, N., Kramer-Schadt, S., Herrmann, M., Trinzen, M., Büttner, I., Niemitz, C. (2008). Habitat selection models for European wildcat conservation. *Biological Conservation* **141**(1): 308–319.

Kupfer, J. A. (2012). Landscape ecology and biogeography Rethinking landscape metrics in a post-FRAGSTATS landscape. *Progress in Physical Geography* **36**(3): 400–420.

Lozano, J., Malo, A. F. (2012). Conservation of the European wildcat (Felis silvestris) in mediterranean environments: A reassessment of current threats. In: Williams, G. S. (ed.). *Mediterranean Ecosystems* pp. 1–31. Nova Science Publishers, Inc.

Malo, A. F., Lozano, J., Huertas, D. L., Virgós, E. (2004). A change of diet from rodents to rabbits (Oryctolagus cuniculus). Is the wildcat (Felis silvestris) a specialist predator? *Journal of Zoology* **263**(4): 401–407.

Melovski, L., Jovanovska, D., Avukatov, V. (2015). *Landscape diversity in Bregalnica watershed. Final report of the project "Ecological Data Gap Analysis* *and Ecological Sensitivity Map Development for the Bregalnica River Watershed"*. Book 4. Skopje, 64 p.

Melovski, L., Jovanovska, D., Hristovski, S. (2019). Landscape diversity in North Macedonia. *Macedonian Journal of Ecology and Environment* **21**(1–2): 35–64.

Melovski, L., Markoski, B., Hristovski, S., Jovanovska, D., Anastasovski, V., Klincharov, S., Velevski, M., Velkovski, N., Trendafilov, A., Matevski, V., Kostadinovski, M., Karadelev, M., Levkov, Z., Kolchakovski, D. (2013). Regional division of the Republic of Macedonia for the needs of biological databases. *Macedonian Journal of Ecology and Environment* **15**(2): 81–111.

Mitchell, M. G. E., Bennett, E. M., Gonzalez, A. (2013). Linking Landscape Connectivity and Ecosystem Service Provision: Current Knowledge and Research Gaps. *Ecosystems* **16**(5): 894–908.

Monterroso, P., Brito, J. C., Ferreras, P., Alves, P. C. (2009). Spatial ecology of the European wildcat in a Mediterranean ecosystem: dealing with small radio-tracking datasets in species conservation. *Journal of Zoology* **279**(1): 27–35.

Pimentel, D., Stachow, U., Takacs, D. A., Brubaker, H. W., Dumas, A. R., Meaney, J. J., O'Neil, J. A. S., Onsi, D. E., Corzilius, D. B. (1992). Conserving Biological Diversity in Agricultural/Forestry Systems. *BioScience* **42**(5): 354–362.

Piñeiro, A., Barja, I., Silván, G., Illera, J. C. (2012). Effects of tourist pressure and reproduction on physiological stress response in wildcats: management implications for species conservation. *Wildlife Research* **39**(6): 532–539.

Portanier, E., Léger, F., Henry, L., Gayet, T., Queney, G., Ruette, S., Devillard, S. (2022). Landscape genetic connectivity in European wildcat (Felis silvestris silvestris): a matter of food, shelters and demographic status of populations. *Conservation Genetics* **23**(3): 653–668.

Ruiz-Villar, H., Morales-González, A., López-Bao, J. V., Palomares, F. (2024). Humans and traffic influence European wildcat behaviour in pastoral landscapes. *Animal Behaviour* **207**: 131–146.

Scolozzi, R., Geneletti, D. (2012). Assessing habitat connectivity for land-use planning: a method integrating landscape graphs and Delphi survey. *Journal of Environmental Planning and Management* **55**(6): 813–830.

Špulerová, J., Petrovič, F. (2012). Historical agricultural landscape as a subject of landscape ecological research. *Hrvatski geografski glasnik* **73**(2.): 155–163.

Taylor, P. D., Fahrig, L., Henein, K., Merriam, G. (1993). Connectivity Is a Vital Element of Landscape Structure. *Oikos* **68**(3): 571.

Thies, C. (1999). Landscape Structure and Biological Control in Agroecosystems. *Science* **285**(5429): 893–895.

Thrush, S. F., Hewitt, J. E., Lohrer, A. M., Chiaroni, L. D. (2013). When small changes matter: the role of cross-scale interactions between habitat and ecological connectivity in recovery. *Ecological Applications* **23**(1): 226–238.

Tischendorf, L., Fahrig, L. (2000). On the usage and measurement of landscape connectivity. *Oikos* **90**(1): 7–19.

Turner, M. G. (1989). Landscape Ecology: The Effect of Pattern on Process. *Annual Review of Ecology and Systematics* **20**: 171–197.

Urzi, F., Šprem, N., Potočnik, H., Sindičić, M., Konjević, D., Ćirović, D., Rezić, A., Duniš, L., Melovski, D., Buzan, E. (2021). Population genetic structure of European wildcats inhabiting the area between the Dinaric Alps and the Scardo-Pindic mountains. *Scientific Reports* **11**(1): 17984.

Velázquez, J., Gutiérrez, J., García-Abril, A., Hernando, A., Aparicio, M., Sánchez, B. (2019). Structural connectivity as an indicator of species richness and landscape diversity in Castilla y León (Spain). *Forest Ecology and Management* **432**: 286–297.

Watts, K., Eycott, A. E., Handley, P., Ray, D., Humphrey, J. W., Quine, C. P. (2010). Targeting and evaluating biodiversity conservation action within fragmented landscapes: an approach based on generic focal species and least-cost networks. *Landscape Ecology* **25**(9): 1305–1318.

Zeller, K. A., McGarigal, K., Whiteley, A. R. (2012). Estimating landscape resistance to movement: a review. *Landscape Ecology* **27**(6): 777–797.

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