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Terrestrial vertebrates of post-coalmining sites in the Donets Basin (Ukraine)

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Terrestrial vertebrates of post-coalmining sites in the Donets Basin (Ukraine). — E. Ulyura, V. Tytar. — An inventory of terrestrial vertebrates in 17 post-coalmining sites in the Donbas region of Ukraine revealed 90 species (2 amphibian, 3 reptile, 69 bird and 16 mammal species). The potential of these sites was confirmed for sustaining and conservation of protected terrestrial vertebrate species. Some relationships were considered between environmental heterogeneity and species richness. These links in terms of GIS-derived variables have not been widely examined across such gradients of human impact on the landscape as post-coalmining sites. We have explored simple measures of geodiversity, which provided a timesaving and financially practical way of measuring abiotic environmental heterogeneity of the study units. In our case, we have found a positive relationship between the topographic wetness index and bird species richness, and a negative relationship between the brightness temperature (minimum) and bird/mammal species richness. A spontaneous succession of post-coalmining sites seems to have enhanced biodiversity and promoted the settlement of specialized and/or endangered species.

Key words: terrestrial vertebrates, coal mining, waste, biodiversity, conservation.

Introduction

The pivotal role of coal mining in shaping the Ukrainian national industrial infrastructure and economy cannot be underestimated. Among other things, it underpins the metallurgical industry of the country with coking coals, the thermal power generation sector with steaming coals, and also supplies both energy carrier and feedstock to the chemicals sector. Ukrainian coal reserves are enormous, at some 33.9 billion metric tonnes, roughly half of which is anthracite and bituminous coals, half lignite and sub-bituminous coals (Coal..., 2015).

Despite this importance, the cost of mining activities to the country in environmental and social terms has also been large. As a prime example, the mining areas surrounding Donetsk constitute one of the most environmentally damaged regions of Ukraine. During operation, waste materials from underground mines are transported to the surface and discarded in large waste dump piles commonly referred to in Ukraine as “terracones.” These piles vary in size, have conical shape and can exceed 80< m in height. The majority of the material in the pile is typically mudstones, shale, limestone, sandstone and sometimes up to 12–15 % of coal in localized areas of the pile. The material in the piles varies in size, from dust to small boulders, with the majority of the fines at the top of the pile and the large material lower in the pile profile. Pile volumes vary from 1 to 8 million m^3 and typically have a footprint ranging from 1 to 30 hectares.

The many hundreds of coalmining sites have been key contributors to this degradation. In the past 20 years or so pursuant to economic restructuring, many mines have ceased activities or have been targeted for closure. For most of these sites, closure is premature and is taking place both before coal reserves are exhausted and before development of proper plans for safe, environmentally responsible and socially robust closure. As such, Ukraine has been faced with an unprecedented occurrence of premature mine closures that have the potential to cause significant adverse impacts on the environment.

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On the other hand, these sites are greatly overlooked and under-appreciated, despite their biological and heritage importance. Like many coal waste sites, they are regarded as "abandoned" or "derelict" waste lands and receive little to no protection to safeguard their future. They face many threats including development, reworking to extract useable resources, inappropriate reclamation and / or remediation, inappropriate or lacking management, etc. As vast portions of countryside become steadily more degraded for wildlife, coal waste sites are becoming increasingly important places for wildlife. These sites may provide a must-needed refuge for a range of species rapidly declining in our modern impoverished landscapes. By linking-up with traditional habitats, they also may act as stepping-stones in the environment, allowing species to move freely across the landscape. However, little is known about the composition and distribution of terrestrial vertebrates within these sites, including reptiles, mammals, and birds. One reason might be that individual sites provide usually limited areas relative to the wide-ranging home ranges inherent to most vertebrate species.

It was also observed that some piles naturally re-vegetate, with some supporting a solid growth of trees and shrubs, while others have been re-contoured and re-vegetated. However, this practice has been minimized due to the lack of funds, so spontaneous succession is successfully taking hold. Animals including vertebrates are known to inhibit or facilitate succession in several ways, e.g., due to grazing, predation, or competition (Walker, del Moral, 2009), therefore in terms of environmental rehabilitation there is a need to fill this gap in our knowledge by exploring the biodiversity of vertebrates.

For this study, we targeted locations in the Donbas area. Due to the large number of post-coalmining sites and their relatively high degree of heterogeneity, any rational decision-making process requires significantly more information regarding their makeup than currently exists. Moreover, while there has been a long period of industrial use for many of these sites, the possibility of their high importance as biodiversity areas cannot be excluded. The aim of this study is to analyze the faunal composition of terrestrial vertebrates in 17 post-coalmining sites, which largely have been left without intervention, thus providing opportunity for spontaneous natural succession.

These differently established sites can vary also in relation to numerous environmental characteristics, which could significantly affect the communities they host. In terms of age, appearance and vegetation, investigated sites can be grouped arbitrarily into the following types (table 1). Unfortunately, access to knowledge describing mining objects is limited. Effective application of computerized geographical information systems (GIS) could be invaluable in the management of such information in the Ukrainian context. Using GIS data, including remote sensing data and habitat characteristics, we addressed the question of which specific landscape types and environmental factors enrich or impoverish their faunal composition. Special attention is drawn to species listed in national and international Red Data Books and Protection Lists.

Materials and methods

Study area and sites

Donbas has a temperate continental climate with clearly-defined seasons. There are big differences between winter and summer temperatures. The average January temperature is –4°C to –6°C. In some parts of the region, it reaches –7°C. During the coldest winters, the temperature can fall to –36°C, while the maximum in summer is 40°C to 42°C. Precipitation in Donbas is 350 to 600 mm annually, which is not sufficient. Spring, the end of summer and autumn are arid, and the rains are intense, localized and brief. Moisture is one of the main limiting factors and therefore grasses dominate natural vegetation (Loza, Nazarenko, 2006). As such, the dry hot summers of the region represent a significant challenge for re-vegetation and re-colonization of damaged sites by terrestrial vertebrates.

The 17 post-coalmining sites used in the study varied in size: from 0.5 hectare to above 55 hectares. Geographic centroids (WGS84 datum) of the sites together with their size and type are presented in table 2.

Table 1. **Types of study sites influenced by quarrying and coal mining activities**
Таблиця 1. **Типи досліджуваних ділянок кар'єрних та вугільних видобуток**

Types		Acronym	Description
Age	1st group	I	Ceased to function before the 1960s
	2nd group	II	Ceased to function before the 1970–1980s
	3rd group	III	Ceased to function after the 1990s
Relief type	Slag heap	S	Single cone-shaped heap with an acute or slightly flattened apex
	Terraced heap	TH	A heap with a flat top (plateau) and / or terraces cut on the slopes
	Heap of a complex relief	HCR	Heap with several different components in the relief (2, 3 peaks, secondary bulk top, plateau, terraces, etc.)
Vegetation	Type A	A	Weakly overgrown with herbaceous vegetation, arboreal and shrubby vegetation is scarce, mainly at the foot / reclamation was not carried out
	Type B	B	Grass cover is moderately developed, woody-shrub vegetation covers 1/3-1/2 of the surface area of the heap / initial stages of reclamation
	Type C	C	Grass cover is practically absent, the whole surface of the dump (except for the top) is overgrown with arboreal and shrubby vegetation / final stages of reclamation

Table 2. **Study sites, their geographic centroids, area and type**
Таблиця 2. **Перелік досліджених відвалів, їх географічні координати, площа та тип**

№	Site name	Longitude	Latitude	Area (ha)	Type
1	Panfilivska	37.729033	48.031395	23.3	III-TH-B
2	Bahmutka-1	37.778461	48.028910	5.3	I-S-C
3	Bahmutka-2	37.771001	48.026993	6.0	I-HCR-B
4	Bahmutka-3	37.772575	48.022771	18.8	II-TH-B
5	Bahmutka-4	37.770864	48.031573	0.5	I-S-A
6	Zasiadko	37.789487	48.037193	6.3	II-HCR-C
7	Kirovska-1	37.724126	47.980474	24.9	III-HCR-A
8	Kirovska-2	37.719802	47.985748	7.2	III-S-A
9	Butovka-Donetska	37.793188	48.065797	10.7	II-HCR-B
10	Gorkogo-1	37.783977	47.996388	1.0	I-S-C
11	Gorkogo-2	37.779466	47.996327	5.4	I-TH-B
12	Maiak	37.759360	48.030413	4.6	II-TH-B
13	Izotova-1	37.991828	48.377547	55.6	II-HCR-A
14	Izotova-2	37.996261	48.373459	16.3	II-HCR-B
15	Zaperevalna	37.877263	47.995213	27.6	III-TH-A
16	Sviatoserafimivska	37.840524	48.027338	11.9	III-HCR-A
17	Vetka	37.797443	48.037476	2.5	II-S-C

Sampling

The named sites were sampled for terrestrial vertebrates between 2007 and 2013. Standard methods for the inventory of amphibians, reptiles, birds, and mammals were employed (Novikov, 1949; Smirnov, 1964; Bibby et al., 2000; Kondratenko, Foroschuk, 2006). In total, 342 days were spent in the field, however most of the surveys (around two thirds) were carried out in the 2nd and 3rd quarters of the year in order to cover the nesting period and migrations of birds. The following analysis is based on pooled inventory data for each investigated site.

Landscape and environmental factors

A plethora of metrics has been developed to quantify landscape patterns, however here we simply focus on habitat configuration as far as many species are sensitive to the size and configuration of habitat patches across a landscape. Spatial configuration refers to the spatial character and arrangement, position, or orientation of patches within the landscape. The most basic measure of configuration is patch size. Shape complexity refers to the geometry of patches: do they tend to be simple and compact, or irregular and convoluted. The most common measures of shape complexity are based on

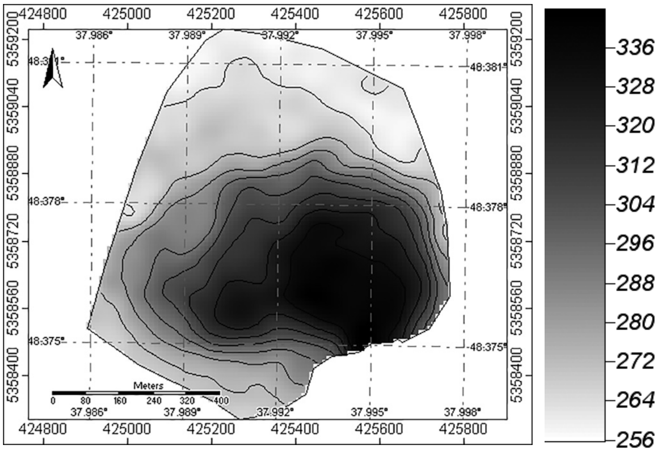

Fig. 1. A digital elevation model (DEM), exemplified by izotova-1 study site; the units of the legend are meters

Рис. 1. Цифрова висотна модель на прикладі дослідженої ділянки Ізотова-1; у легенді одиниці виміру в метрах.

the relative amount of perimeter per unit area, usually indexed in terms of a perimeter-to-area ratio. For our purpose we used the measures implemented in the module 'Polygon Shape Indices' implemented in SAGA GIS (Conrad, 2006). These namely are: Area (A), Perimeter (P), P/A, P/sqrt (A), Maximum Distance (D), D/A, D/sqrt (A) and Shape Index (SI).

A digital elevation model (DEM) was used as input for capturing topographic variables. The DEM was aggregated from the 30 seconds (~30 m) NASA Shuttle Radar Topography Mission (SRTM) DEM (Fig. 1) (https://www2.jpl.nasa.gov/srtm). Topography heterogeneity on a local scale plays an important role in productivity and diversity (Kubota et al., 2004). Topographic features affect nutrient and soil fauna distribution, which consequently influences the plant community composition (Walmsley et al., 2017).

A number of terrain features were extracted, which characterize the habitat from different perspectives. These namely are: slope, aspect and topographic wetness index (TWI). SAGA GIS software was effectively used in this process.

Elevation, slope and aspect have been demonstrated to be beneficial predictors for the temporal and spatial distributions of variables such as precipitation and radiation, which highly influence vegetation growth and species composition (Stage, Salas, 2007). The TWI factor accounts for the propensity of a site to be wet or dry, has a strong correlation with landform classes and is widely used to explain water level, sediment content and soil moisture of the area (Wilson, Gallant, 2000). TWI can also be seen as a proxy for temporary or seasonal water bodies (Steger et al., 2017).

We used a Landsat 8 satellite images (path 176 / rows 26 and 27) taken on the 18th of May 2014, freely acquired from the U.S. Geological Survey georeferenced GeoTIFF files at a 30 m resolution via the Libra browser for opening Landsat 8 satellite imagery (https://libra.developmentseed.org). These images encompassing the study area had the minimum cloud coverage (0.01 %). Images from May were chosen so that vegetation growth in the area could be studied before the summer drought. A number of environmental variables were extracted from the Landsat image: the enhanced vegetation index (EVI) and tasselled cap transformations. EVI values range between –1 and +1, where negative values generally indicate water, 0 indicates no green vegetation, and larger positive values indicate increasing density/biomass of green vegetation, with values typically ranging from 0.05 for sparse vegetative cover to 0.7 for dense vegetative cover.

For each image, we applied the Tasseled Cap (TC) transformation to reduce the dimensionality of Landsat's six optical spectral bands into three orthogonal indices that are easier to visualize and interpret. The design of the TC transformation specifically emphasizes inherent data structures that capture key physical properties of vegetated systems that can be compared both within and across scenes (Crist, Kauth, 1986). TC Brightness (TCB) generally captures variation in overall reflectance, or something akin to albedo; TC Greenness (TCG) captures variability in green vegetation; and TC Wetness (TCW) responds to a combination of moisture conditions and vegetation structure (Crist, Cicone, 1984; Cohen, Spies, 1992).

We also used the Landsat-8 thermal bands i.e., Band 10 and Band 11 to calculate the brightness temperature over the sites. Brightness temperature is a measure of the ground surface temperature (^{o}C).

Though surface temperature is a significantly dynamic characteristic, a snapshot of the area may give an insight to differences between the study sites regarding their "hotness."

Statistical analyses

The data collected during the whole study period were analysed in PAST statistical software (Hammer et al., 2001). Univariate statistics were calculated for features characterizing each of the study sites. The generalized linear model (GLM) module in PAST was used to explore the relationships between the landscape and environmental features of the post-coal mining sites and the species richness of the terrestrial vertebrate communities they hold. This module computes a basic version of the GLM, for a single explanatory variable. GLM allow a range of model specification distributions other than the normal distribution for the random component, also avoiding the constraint imposed by the assumption of linearity between the dependent and independent variables. In the present case, a Poisson error distribution for the number of species found at a specific coal mining waste site was assumed. It was linked to the considered features via a logarithmic link function. The module also calculates a G-statistic, which is approximately chi-squared with one degree of freedom, giving a statistical significance for the slope.

With a growing availability of spatial, in particular gridded, environmental data sets, which are often correlated or redundant, a data reduction was considered. Due to the high levels of correlations between many environmental variables, we filtered the initial variable set of features based on the results of multi-colinearity analysis by calculating the Variance Inflation Factor (VIF): $VIF = 1 / (1 - R^2)$, where R^2 is the coefficient of determination. VIF values higher than 10 are considered to lead to problematic levels of multi-collinearity (Craney, Surles, 2002). Features with VIF values that exceeded 10 were not used in the analysis.

In the analysis, we have separately considered the species richness of amphibians, reptiles, birds and mammals encountered in each of the study sites. Significant ($p < 0.05$) results of the comparisons are included in the text and considered in the results interpretations.

Results

A total of 90 terrestrial vertebrate species belonging to 4 classes were recorded during the course of the study (Table 3): 2 amphibian, 3 reptile, 16 mammal and 69 bird species. Among the recorded species, 3 species belong to the Near Threatened (NT) category of the IUCN.

These are one reptile species, the European pond turtle (*Emys orbicularis*), which is listed as well under the same category in the IUCN Red List for Europe, and 2 bird species, the corncrake (*Crex crex*) and the great snipe (*Gallinago media*). Two species are mentioned in the IUCN Red List (Europe). Besides the European pond turtle, the other species is the northern lapwing (*Vanellus vanellus*), belonging to the category "vulnerable" (VU).

According to Godlevska et al. (2010), 73 species are protected under the Bern Convention: 2 amphibians, 3 reptile species, 4 mammals, and 64 bird species (46 are listed in Annex II and 27 — in Annex III of the convention); 22 species under the Bonn Convention: 2 bat species, the serotine bat (*Eptesicus serotinus*) and Kuhl's pipistrelle (*Pipistrellus kuhlii*), and 20 birds (5 are listed in both Annexes I and II of the convention, 17 — in Annex II); 3 species of birds of prey are in the CITES list: the Eurasian sparrowhawk (*Accipiter nisus*), common kestrel (*Falco tinnunculus*) and the long-eared owl (*Asio otus*) (Annex II).

Nation-wide legal protection under the Red Data Book of Ukraine have 3 species: the mentioned bat species are assigned to the category "vulnerable" (VU), and the great snipe is considered to be declining (category D). In addition, 37 species are listed in regional (or "oblast", referring to one of Ukraine's 24 primary administrative units) red data books: these together include 3 reptile, 3 mammal and 31 bird species.

Table 3. **List of terrestrial vertebrate species and their nature conservation status**
Таблиця 3. **Перелік видів наземних хребетних та їх охоронний статус**

Species	Sites	Red Lists						
		IUCN	ERL	BeC	BoC	CITES	RDB	RRDB
Amphibians								
Bufo viridis Laurenti, 1768	1			II				
Pelophylax ridibundus Pallas, 1771	1, 3, 4, 7–9, 12, 16			III				
Reptiles								
Emys orbicularis (L., 1758)	3, 7	NT	NT	II				K L S Kh
Lacerta agilis L., 1758	1–9, 12–17			II				M
Natrix natrix (L., 1758)	1, 3, 4, 7–9			III				D
Mammals								
Erinaceus concolor Martin, 1838	1, 2, 6–9, 13–15							
Ondatra zibethica (L., 1766)	3, 4							
Microtus levis Miller, 1908	13							
Sylvaemus sylvaticus (L., 1758)	1–9, 12, 15							
Sylvaemus uralensis (Pallas, 1811)	13, 14							
Rattus norvegicus (Barkenhout, 1769)	2, 4, 6, 9, 14–16							
Lepus europaeus Pallas, 1778	1, 3, 4, 7, 9, 13, 15, 16			III				
Canis familiaris L., 1758	1–17							
Vulpes vulpes (L., 1758)	13, 14							
Martes foina (Erxleben, 1777)	1, 9, 15			III				M
Meles meles (L., 1758)	14			III				P S
Felis catus L., 1758	1, 2, 5, 7–9, 11							
Capreolus capreolus (L., 1758)	14			III				
Sus scrofa L., 1758	13, 14							
Eptesicus serotinus (Schreber, 1774)	1–5			II	II		VU	S Kh
Pipistrellus kuhlii (Kuhl, 1817)	1-6, 9, 15			II	II		VU	
Birds								
Podiceps ruficollis (Pallas, 1764)	3			II				D L S Kh
Ixobrychus minutus (L., 1766)	1, 3, 7, 8			II	II			K S Kh
Anas querquedula (L., 1758)	9			III	I			Kh
Anas platyrhynchos (L., 1758)	1, 3, 4, 7–9, 16			III	I			Kh
Accipiter nisus (L., 1758)	4, 12-14, 16			II	I	II		M
Falco tinnunculus L., 1758	1-5, 7, 8, 13-15			II	II	II		D L M P S Kh
Coturnix coturnix (L., 1758)	9			III	II			M Kh
Phasiunus colchicus L., 1758	1-4, 8, 9, 12-16			III				
Crex crex (L., 1758)	1, 9	NT		II				D K L
Fulica atra L., 1758	1, 3, 4, 7–9, 16			III	II			
Gallinula chloropus (L., 1758)	1, 3, 4, 7–9			III				Z
Vanellus vanellus (L., 1758)	16		VU	III	II			Kh
Gallinago media (Latham, 1787)	9	NT		II	I		D	D L S Kh
Scolopax rusticola L., 1758	1, 4, 9			III	I			K S Kh
Larus cachinnans Pallas, 1811	9, 15, 16							
Columba livia Gmelin, 1789	1–15, 17			III				
Streptopelia decaocto (Frivaldszky, 1838)	2, 3, 5, 6, 8–10, 12, 15, 17			III				
Streptopelia turtur (L., 1758)	9, 14			III				
Cuculus canorus L., 1758	2, 4, 7, 9, 12–14			III				
Asio otus (L., 1758)	9, 14			II		II		M
Apus apus (L., 1758)	1–17			III				
Alcedo atthis (L., 1758)	7–9, 12			II				K Kh
Dendrocopos major (L., 1758)	7, 9, 11, 14			II				
Dendrocopos syriacus (Hemprich et Ehrenberg, 1833)	1–4, 6, 7, 10, 12, 15-17			II				
Hirundo rustica L., 1758	4, 7-9, 13, 14, 16			II				
Delichon urbica (L., 1758)	1-6, 9-12, 15, 17			II				
Eremophila alpestris (L., 1758)	9			II				
Galerida cristata (L., 1758)	1, 16			III				Z

Species	Sites	Red Lists						
		IUCN	ERL	BeC	BoC	CITES	RDB	RRDB
Alauda arvensis L., 1758	7–9, 13, 15			III				
Motacilla flava L., 1758	13, 15			II				
Motacilla alba L., 1758	1, 2, 4, 9, 15, 16			II				
Lanius collurio L., 1758	2, 4, 5, 7–9, 13, 15, 17			II				
Oriolus oriolus (L., 1758)	3, 4, 7, 8			II				
Sturnus vulgaris L., 1758	1-10, 12, 15, 16							
Garrulus glandarius (L., 1758)	1–10, 14							
Pica pica (L., 1758)	1–17							
Corvus frugilegus L., 1758	1–6, 9–17							
Corvus cornix L., 1758	14, 15							
Corvus corax L., 1758	1, 4–6			III				
Troglodytes troglodytes (L., 1758)	9			II				
Acrocephalus schoenobaenus (L., 1758)	1			II				Z Kh
Acrocephalus arundinaceus (L., 1758)	1, 3, 4, 7-9			II				Z
Sylvia atricapilla (L., 1758)	7, 13			II				Kh
Sylvia borin (Boddaert, 1783)	1, 6			II				Z Kh
Sylvia communis Latham, 1787	2, 4, 9, 11, 15			II				Kh
Phylloscopus collybita (Vieillot, 1817)	1, 2, 14, 17			II				
Phylloscopus trochilus (L., 1758)	1, 2, 9, 10, 14			II				
Muscicapa striata (Pallas, 1764)	1			II	II			Z Kh
Ficedula albicollis (Temminck, 1815)	1, 9, 13, 14			II	II			Z Kh
Saxicola rubetra (L., 1758)	4, 8, 9, 12			II	II			Kh
Oenanthe oenanthe (L., 1758)	1–4, 6–11, 13–17			II	II			
Phoenicurus ochruros (S. G. Gmelin, 1774)	1, 2, 4–10, 15, 16			II	II			
Erithacus rubecula (L., 1758)	9			II	II			Kh
Luscinia luscinia (L., 1758)	2, 12			II	II			Kh
Luscinia svecica (L., 1758)	1, 4, 7-9, 12			II	II			Z
Turdus merula L., 1758	2, 4, 10			III	II			Kh
Turdus philomelos C. L. Brehm, 1831	7-9, 13-15			III	II			Kh
Remiz pendulinus (L., 1758)	16			II				Z M S
Parus caeruleus L., 1758	3, 4, 10, 13, 14			II				
Parus major L., 1758	1-7, 9–17			II				
Passer domesticus (L., 1758)	1, 2, 5–10, 15, 17							
Passer montanus (L., 1758)	1, 2			III				
Fringilla coelebs L., 1758	1, 2, 4, 6, 12–15, 17			III				
Spinus spinus (L., 1758)	1, 2			II				S
Chloris chloris (L., 1758)	1, 2, 4, 6, 9–14, 17			II				
Carduelis carduelis (L., 1758)	1–5, 7–9, 11–14, 16			II				
Acanthis cannabina (L., 1758)	1, 4, 5, 7, 9, 11–15, 17			II				
Pyrrhula pyrrhula (L., 1758)	1			III				S
Coccothraustes coccothraustes (L., 1758)	2, 4, 6, 9			II				

Note. IUCN — IUCN Red List; ERL — European Red List categories; BeC — Bern Convention; BoC — Bonn Convention; RDB — Red Data Book of Ukraine; RRDB — Regional Red Data Books, Ukraine. Sites — number of site according to Table 2; IUCN categories: NT — near threatened; European Red List categories — NT — near threatened, VU — vulnerable; Bern Convention — II — Annex II, III — Annex III; Bonn Convention: I — Annex I, II — Annex II; CITES — II — Annex II; Red Data Book of Ukraine categories: VU — vulnerable, D — declining; Regional Red Data Books (refers to oblasts in Ukraine): K — Kyivska, D — Dnipropetrovska, Z — Zaporizska, L — Luhanska, M — Mykolaivska, P — Poltavska, S — Sumska, Kh — Khersonska.

Table 4. **The Generalized Linear Modelling for considered variables of habitat features (VIF > 10) affecting species richness (p > 0.05)**

Таблиця 4. **Результати узагальненого лінійного моделювання для розглянутих змінних характеристик середовища (VIF > 10), що впливають на видове багатство (p > 0.05)**

Group	Feature variable	Slope	Intercept	G-statistic	P (slope = 0)
Birds	Area (A)	0.742	3.090	4.61	0.032
	Perimeter-area ratio (P/A)	–15.827	3.447	13.33	0.000
	Topographic wetness index (mean)	0.282	1.690	4.94	0.026
	Brightness temperature (minimum)	–0.156	7.605	20.89	0.000
Mammals	Brightness temperature (minimum)	–0.253	8.706	9.97	0.002

The results from analysing habitat size, shape and environmental factors affecting the species richness are summarized in Table 4. All those environmental factors not included there had no significant effects in the particular models or were redundant. These effects were found mainly for birds (in one case for mammals), for which there was sufficient quantitative data.

Discussion

Ecosystem disturbance is one of the major phenomena in recent times, which alters the relationship of organisms and their habitat in time and space. The extraction of mineral resources is one of the major factors for ecosystem disturbances and survival of wildlife. Nevertheless, growing evidence that exhausted sites constitute biodiversity refuges hosting large numbers of rare and declining species of various organisms has changed the traditionally negative view of these post-industrial barrens (Young, 2000; Harabiš et al., 2013). Mines or industrial deposits are highly valuable for spiders, insects (wasps, beetles, and butterflies), plants, birds, amphibians, or bats (Řehounková et al., 2011). Recently, a complex study of plants and several arthropod groups has shown that the spontaneously developed sites host various endangered species. On the contrary, no endangered plants and arthropods occur in the technical reclaimed parts of the heaps since they are colonized by common generalists (Tropek et al., 2012). In this respect, fewer studies focus on terrestrial vertebrates (Lameed, Ayodele, 2010). Of particular relevance to the aim of this study, the results showed that the post-coal mining sites today act as refuges for many species of terrestrial vertebrates, some of which have high conservation value.

Numerous researchers have explored how abiotic factors are related to species' diversity and distributions (Lawler et al., 2015), and the relationship between environmental heterogeneity and species richness is well established (Stein et al., 2014). However, these links in terms of GIS-derived variables have not been widely examined across such gradients of human impact on the landscape as post-coal mining sites. Here we have explored simple measures of geodiversity (Hjort et al., 2012), which provided a timesaving and financially practical way of measuring abiotic environmental heterogeneity of the study units.

Shape features may have a critical effect on the ecological roles of patches. For instance, patch size has been shown to be important in influencing bird species diversity (Diamond, May, 1976; Bellamy et al., 1996). Patch area is generally considered one of the most important factors, because larger sites often exhibit richer landscape types, lower edge effects, and, therefore, host more bird species (Suarez-Rubio, Thomlinson, 2009). Patch area is also an important variable affecting habitat occupancy (Samson, Knopf, 1980; Vickery et al., 1994) and colonization. In our case, we find a clear positive relationship between bird species richness and the size of the study sites (Table 4), assuming larger sites may have more habitat diversity and edge effects are abated.

Because patch shape, along with area, determines the amount of habitat exposed to edges, patch shape may have a significant effect on habitat occupancy by birds. Among birds, which are often strongly territorial, perch availability (Yosef, Grubb, 1994) and food and nesting sites appear to be particularly relevant to territory configuration (Adams, 2001; Rolando, 2002). Patches of equal area may also vary significantly for area exposed to edges. The relative measure such as perimeter-area ratio accounts for patch area exposed to edges without requiring a subjective estimation of the distance that edge effects extend into a patch. Patches with elongated shapes or indented perimeters have higher perimeter–area ratios than patches of the same area with compact shapes and unbroken perimeters. C. J. Helzer and D. E. Jelinski found that both patch area and perimeter–area ratios were significant predictors of bird species richness, however perimeter–area ratio had a consistently stronger correlation with both species richness and probability of occurrence than did patch area (Helzer, Jelinski, 1999). Our findings in part of species richness are fully consistent with conclusions made by these authors (Table 4); we too join their opinion that species–area relationships most likely are explained by a combination of the habitat diversity and fragmentation models.

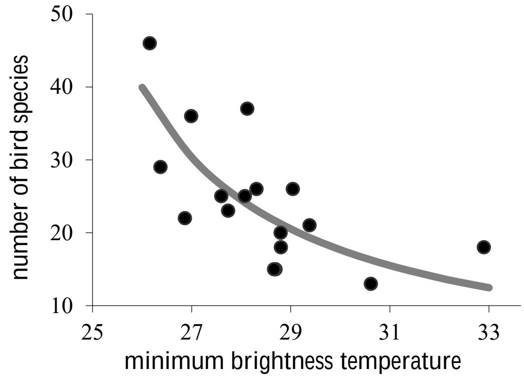

Fig. 2. The bird species richness in relation to brightness temperature of the ground surface temperature (°C).

Рис. 2. Залежність видового багатства птахів від температури яскравості температури поверхні землі (°C).

Within-site habitat composition is also likely to affect the bird community. For instance, bird species richness has been found to be strongly associated with the topographic wetness index (Olivier et al., 2017). In our case, we have found a positive relationship the topographic wetness index and bird species richness indicating that depressions where the water concentrates may indeed be attracting more birds. The same could relate to other taxa, for instance the European pond turtle (Fritz, Chiari, 2013).

Finally, the brightness temperature of the ground surface temperature we measured may be due not only to insolation but as well by combustion. The surface of a burning coal tip has a temperature between 25°C and 60°C, and this can reach above 100°C at a shallow depth. The areas where there is burning have a sparse vegetation and are free of snow in winter, however seem generally to be avoided by both birds and mammals (Table 4, Fig. 2), which by large are preferring cooler places.

Conclusion

Our study confirmed a potential of the post-coal mining landscape for sustaining and conservation of numerous species of terrestrial vertebrates in the Donbas region of Ukraine. Postmining areas comprise valuable surrogate habitats for sustaining biodiversity, including among birds. Indeed, out of the 69 bird species found in this study 61, according to the Bern Convention, are in need of protection at the European scale.

Spontaneous succession seems to have enhanced biodiversity and promoted the settlement of specialized and/or endangered species. By providing complete successional series, they support high β-diversity of the region (Harabis, Dolny, 2012).

Several characteristics related to microhabitat structure were also shown to be important for forming of the assemblages, but to understand the full implications of wildlife response on the habitat more extensive and in-depth research is needed to document the demography (reproduction, survival, immigration, emigration) of the colonizing species. Comprehensive research in connecting geo- and biodiversity deserves further attention in habitat conservation and restoration strategies. In this respect, simple measures of geodiversity derived from digital elevation models and remote sensing may be of great help.

In the future, long-term monitoring plans should be designed to evaluate the impacts of coal mining in communities of terrestrial vertebrates. Long-term monitoring in these must-needed refuges should focus on the ecology of species, especially those considered rare and habitat specialists.

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