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TERRESTRIAL VERTEBRATES OF POST-QUARRYING SITES IN THE DONBAS REGION OF UKRAINE

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Terrestrial Vertebrates of Post-Quarrying Sites in the Donbas Region of Ukraine. Ulyura, E., Tytar, V.— An inventory of terrestrial vertebrates in six post-quarrying sites in the Donbas Region of Ukraine revealed 104 species (2 amphibian, 6 reptile, 78 bird and 18 mammal species). The potential of these sites was confirmed for sustaining and conservation of numerous species of terrestrial vertebrates; some relationships were considered between environmental heterogeneity and species richness.

Key words: terrestrial vertebrates, quarry, biodiversity, conservation.

Introduction

The extraction of rock materials in open-pit quarries represents one of the major anthropogenic impacts on the Earth surface. Regardless of the method used and the resources available, it affects land cover at the site of extraction (Haigh, 2000), leaving behind multiple damages that stretch over a wide range of land. The impacts of quarrying activities affect all aspects of the environment, including lithosphere, atmosphere, hydrosphere and biosphere, leading to the destruction of habitats and loss of biodiversity. As a general rule, impacts of quarrying are classically regarded as threats and potentially damaging to the environment and, in particular, to biodiversity (e. g., Thornton, 1996; Langer, 2001; Lameed, 2011). On the other hand, these sites are greatly overlooked and under-appreciated, despite their biological and heritage importance. Like many quarry sites, they are regarded as 'abandoned' or 'derelict' waste land 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 absence of management etc. This general disapproval is opposed by an understanding which has arisen since the end of the 1970s, namely that mineral extraction sites which have been closed down may take on important functions in the environment of intensely utilized land cultivated by man. Closed down mineral extraction sites which have not been restored by topsoil application,

Table 1. Types of study sites impacted by quarrying and coal mining activities

		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.
		Appearance
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.

sowing and plantation, contribute to sustainably increase and safeguard biodiversity just through the existence of habitats significant within a habitat network system. They also may stabilize the surrounding ecosystems. Ecological and botanical studies of quarries in various geological and environmental arrangements have revealed the ecological potential and biological interest of post-quarrying sites after spontaneous re-vegetation (e. g., Jefferson, 1984; Frochot, Godreau, 1995; Benes et al., 2003). All these studies point to the positive effects of quarrying on biodiversity, because abandoned quarries act as refuges for many plant and animal communities, including a range of rare and/or endangered species of high conservation value (Bétard, 2013).

Re-vegetation of dis-used sites results in the establishment of plant communities and assemblages of small animals such as invertebrates, generally found in abundance on spontaneous successional stands (Hendrychová et al., 2008). On the other hand, little is known about the composition and distribution of terrestrial vertebrates, including reptiles, mammals and birds. One reason might be that individual open-pit quarries provide usually limited areas relative to the wide-ranging home ranges inherent to most vertebrate species. Animals including vertebrates are known to inhibit or facilitate succession in several ways, e.g., due to grazing, predation or competition (Walker, del Moral, 2003), therefore there is a need to close this gap in our knowledge. For this study, we targeted locations in the Donbas area of Ukraine.

The Donbas (Ukrainian: Донбас) or Donbass (Russian: Донбасс) is a historical, cultural, and economic region in eastern Ukraine. The word "Donbas" is a portmanteau formed from Donets Basin (Ukrainian: Донецький басейн, translit. Donetskyi basein; Russian: Донецкий бассейн, Donetskiy bassein), which refers to the Siverskyi Donets River that flows through it. Multiple definitions of the region's extent exist, but the most common definition in use today refers to the Donetsk and Luhansk oblasts of Ukraine. Donbas is dominated by heavy industry, such as coal mining, open-pit quarrying, metallurgy etc. Despite this importance, the cost to the country in environmental terms has also been large. Today Donbas is one of the most environmentally damaged regions of the Ukraine and coal mining activities together with the extraction of other aggregates have been one of the key contributors to this degradation. This encompasses the ongoing environmental effects of the many mine spoil dumps, dis-used quarries etc. that sculpture the Ukrainian landscape. Because of their makeup, positioning and condition, these sites are usually seen to affect society and the natural media (air, water, subsurface etc.) negatively. This stated, many of these also have various values that may be leveraged. Due the large number of such 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. In this light, the literature, for instance, indicates the establishment of rich wetlands in subsidence areas (Loza, Nazarenko, 2006).

The aim of this study is to analyze the faunal composition of terrestrial vertebrates in six dis-used or largely dis-used open-pit quarries, which 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 impacted by both quarrying and coal mining[1] activities can be grouped arbitrarily into the following types (table 1).

Using GIS data on habitat characteristics, we also addressed the question of which specific landscape 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.

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[1] Terrestrial vertebrates of impacted by coal mining activities will be a subject of a separate paper.

Materials and methods

Study area and sites. The study was lies in the Steppe zone of south-eastern Ukraine. This is a relatively mild, warm and dry (mean annual temperatures: 7–9 ° C, annual precipitation: 500–620 mm) lowland area (about 1100 sq. km, mean altitude 270 m a. s. l.). In this area, under a continental-temperate climate, moisture is the one of the main limiting factors and where grasses (graminids) 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 post-quarrying sites by terrestrial vertebrates.

The six chosen for the study quarry sites vary in size: from above 8 sq. km to less than a half of a square km. Geographic centroids (WGS84 datum) of the sites together with their size, type (according to table 1) and geological deposits are presented in table 2.

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, 347 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 of birds and the time when they are on migration. The following analysis is based on pooled inventory data for each 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 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) (exemplified in fig. 1) 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. Topography heterogeneity on a local scale plays an important role in productivity and diversity (Kubota et al., 2004).

Table 2. **Study sites, their geographic centroids, area, type and geological deposits**

Site name	Longitude	Latitude	Area (sq. km)	Type	Geological deposits
Amvrosievka	38.511600	47.816842	8.57	II-HCR-B	Marl
Bylbasovka	37.417195	48.837083	1.05	III-TH-A	Chalk
Dokuchaevsk	37.716067	47.740780	6.71	III-HCR-B	Flux dolomite
Novotroitske	37.574494	47.733989	3.63	III-HCR-B	Limestone, dolomite
Raygorodok	37.711508	48.927015	2.47	II-HCR-A	Chalk, marl
Seversk	38.066790	48.924583	0.47	III-HCR-A	Dolomite

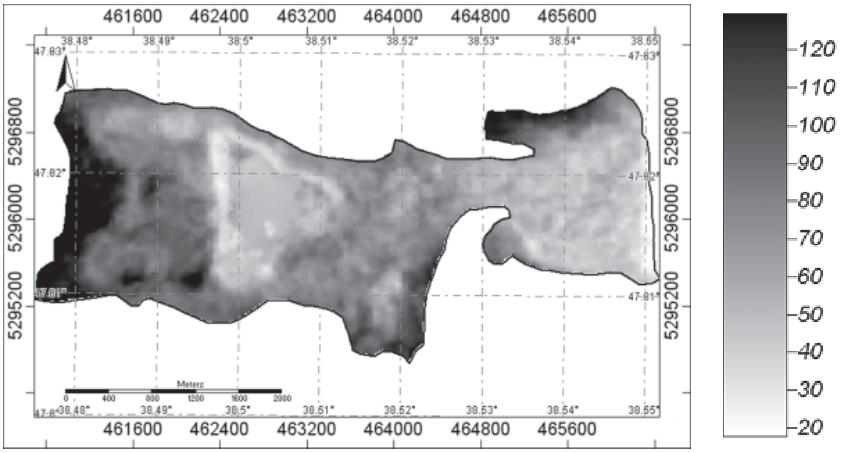

Fig. 1. A digital elevation model (DEM): exemplified for the Amvrosievka quarry site (legend: meters above sea level).

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, 2014).

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 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). Greeness and EVI are correlated, therefore only EVI was considered.

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

Statistical analyses. The data collected during the whole study period were analyzed in PAST statistical software (Hammer et al., 2001). Univariate statistics — mean standard deviation (SD), minimum (min) and maximum (max) — were calculated for features characterizing each of the quarry sites. The generalized linear model (GLM) module in PAST was used to explore the relationships between the landscape and environmental features of the quarries 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 quarry 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. For highly correlated variables with significant Spearman correlation coefficients ($p < 0.05$), we removed the variable with the lower predictive power.

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

Results

A total of 104 terrestrial vertebrate species belonging to 4 classes were recorded during the course of the study (table 3): 2 amphibian, 6 reptile, 18 mammal and 78 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*). Five species are mentioned in the IUCN Red List (Europe). Besides the European pond turtle, these are one reptile species, the steppe runner lizard (*Eremias arguta*) (NT), and 3 bird species, the black kite (*Milvus migrans*), the grey partridge (*Perdix perdix*) and the northern lapwing (*Vanellus vanellus*), belonging to the category "vulnerable" (VU). According to Godlevska et al. (2010), 85 species are protected under the Bern Convention: 2 amphibians, 6 reptiles, 8 mammals and 69 birds (55 are listed in Annex II and 30 — in Annex III of the convention); 25 — under the Bonn Convention: 2 bat species, Kuhl's pipistrelle (*Pipistrellus kuhlii*) and the common noctule (*Nyctalus noctula*), and 23 birds (7 are listed in both annexes I and II of the convention, 18 — in Annex II); 5 species of birds of prey are in the CITES list: the black kite, the western marsh harrier (*Circus aeruginosus*), common buzzard (*Buteo buteo*), common kestrel (*Falco tinnunculus*) and the long-eared owl (*Asio otus*) (Annex II). Legal protection nation-wide under the Red Data Book of Ukraine have 5 species; 4 of them, the smooth snake (*Coronella austriaca*), the two mentioned above bat species and the black kite are assigned to the category "vulnerable" (VU), one species, the great snipe,

Table 3. List of terrestrial vertebrate species and their nature conservation status

Species	Sites	IUCN Red List	IUCN Red List Category (Europe)	Bern Convention	Bonn Convention	CITES	Red Data Book of Ukraine	Regional Red Data Books, Ukraine
1	2	3	4	5	6	7	8	9
Amphibians								
Bufo viridis Laurenti, 1768	4, 6			II				
Pelophylax ridibundus Pallas, 1771	1, 3, 4			III				
Reptiles								
Emys orbicularis (Linnaeus, 1758)	1	NT	NT	II				KLSKh
Lacerta agilis Linnaeus, 1758	1–6			II				M
Eremias arguta Pallas, 1773	2, 5		NT	III				DLMPKh
Coronella austriaca Laurenti, 1768	1, 6			II			VU	S
Natrix natrix (Linnaeus, 1758)	1, 4, 6			III				D
Natrix tessellata Laurenti, 1768	1, 3, 4			II				PKh
Mammals								
Erinaceus concolor Martin,1838	1, 3, 6							
Crocidura suaveolens (Pallas, 1811)	4			III				DZL
Spalax microphthalmus Guldenstaedt, 1770	2–4, 6							S
Ondatra zibethica (Linnaeus, 1766)	4							
Microtus levis Miller, 1908	2–6							
Sylvaemus uralensis (Pallas, 1811)	2–6							
Sylvaemus tauricus (Pallas, 1811)	6							
Lepus europaeus Pallas, 1778	1–6			III				
Canis familiaris Linnaeus, 1758	3, 6							
Vulpes vulpes (Linnaeus, 1758)	1–4, 6							
Martes foina (Erxleben, 1777)	3, 5			III				M
Mustela nivalis Linnaeus, 1766	1			III				MS
Meles meles (Linnaeus, 1758)	4, 6			III				PS
Felis catus Linnaeus, 1758	2							
Capreolus capreolus (Linnaeus, 1758)	1, 3			III				
Sus scrofa Linnaeus, 1758	3, 4							
Pipistrellus kuhlii (Kuhl, 1817)	3, 4			II	II		VU	
Nyctalus noctula (Schreber, 1774)	6			II	II		VU	SKh
Birds								
Ixobrychus minutus (Linnaeus, 1766)	3, 4			II	II			KSKh
Anas querquedula (Linnaeus, 1758)	3, 4			III	I, II			Kh
Anas platyrhynchos (Linnaeus, 1758)	1, 3, 4			III	I, II			Kh
Milvus migrans (Boddaert, 1783)	1, 2		VU	II	I, II	II	VU	ZDKLMSKh
Circus aeruginosus (L., 1758)	3, 4			II	I, II	II		MKh
Buteo buteo (Linnaeus, 1758)	1, 5, 6			II	I, II	II		Kh
Falco tinnunculus Linnaeus, 1758	1–6			II	II	II		DLMPSKh
Perdix perdix (Linnaeus, 1758)	2–4, 6		VU	III				MPKh
Coturnix coturnix (Linnaeus, 1758)	1			III	II			MKh
Phasianus colchicus Linnaeus, 1758	1, 3, 4			III				

1	2	3	4	5	6	7	8	9
Crex crex (Linnaeus, 1758)	4	NT		II				DKL
Fulica atra Linnaeus, 1758	1, 3, 4			III	II			
Gallinula chloropus (Linnaeus, 1758)	1, 3, 4			III				Z
Charadrius dubius Scopoli, 1786	1, 5, 6			II	II			Kh
Vanellus vanellus (Linnaeus, 1758)	3, 4		VU	III	II			Kh
Gallinago media (Latham, 1787)	1	NT		II	I, II		D	DLSKh
Scolopax rusticola Linnaeus, 1758	1			III	I, II			KSKh
Larus ridibundus L.,1766	4			III				
Larus cachinnans Pallas, 1811	1							
Columba livia Gmelin, 1789	1–5			III				
Streptopelia decaocto (Frivaldszky, 1838)	3, 4, 6			III				
Cuculus canorus Linnaeus, 1758	1, 3, 4, 6			III				
*Asio otus (*Linnaeus, 1758)	2, 3			II		II		M
Apus apus (Linnaeus, 1758)	1, 3, 4			III				
Alcedo atthis (L., 1758)	3			II				KKh
Merops apiaster Linnaeus, 1758	2–6			II	II			ZSKh
Picus canus Gmelin, 1788	6			II				D
Dendrocopos major (Linnaeus, 1758)	1, 6			II				
Dendrocopos syriacus (Hemprich et Ehrenberg, 1833)	3, 4			II				
Riparia riparia (Linnaeus, 1758)	3, 6			II				
Hirundo rustica Linnaeus, 1758	1-6			II				
Eremophila alpestris (Linnaeus, 1758)	5			II				
Melanocorypha calandra (Linnaeus, 1766)	2, 5			II				DSKh
Galerida cristata (Linnaeus, 1758)	1, 3, 4			III				Z
Alauda arvensis Linnaeus, 1758	2–6			III				
Motacilla flava Linnaeus, 1758	1–6			II				
Motacilla alba Linnaeus, 1758	4, 6			II				
Lanius collurio Linnaeus, 1758	1–6			II				
Sturnus vulgaris Linnaeus, 1758	3–6							
Garrulus glandarius (Linnaeus, 1758)	1, 2, 5							
Pica pica (Linnaeus, 1758)	1–6							
Corvus monedula Linnaeus, 1758	1							
Corvus frugilegus Linnaeus, 1758	1–5							
Corvus cornix Linnaeus, 1758	6							
Corvus corax Linnaeus, 1758	1, 6							
Troglodytes troglodytes (Linnaeus, 1758)	1			II				
Acrocephalus schoenobaenus (Linnaeus, 1758)	1			II				ZKh
Acrocephalus arundinaceus (Linnaeus, 1758)	1, 3, 4			II				Z
Sylvia atricapilla (Linnaeus, 1758)	1, 3, 6			II				Kh
Sylvia borin (Boddaert, 1783)	2–4			II				ZKh
Sylvia curruca (Linnaeus, 1758)	1			II				D
Sylvia communis Latham, 1787	2, 4, 5			II				Kh
Phylloscopus collybita (Vieillot, 1817)	4			II				
Phylloscopus trochilus (Linnaeus, 1758)	1			II				
Muscicapa striata (Pallas, 1764)	4			II	II			ZKh
Saxicola rubetra (Linnaeus, 1758)	2–3			II	II			Kh
Saxicola torquata (Linnaeus, 1766)	6			II	II			D
Oenanthe oenanthe (Linnaeus, 1758)	1–6			II	II			
Phoenicurus ochruros (S. G. Gmelin, 1774)	1, 3, 4, 6			II	II			
Erithacus rubecula (Linnaeus, 1758)	4			II	II			Kh
Luscinia luscinia (Linnaeus, 1758)	3, 4			II	II			Kh
Luscinia svecica (Linnaeus, 1758)	1–4			II	II			Z
Turdus philomelos C. L. Brehm, 1831	3, 4			III	II			Kh
Remiz pendulinus (Linnaeus, 1758)	4			II				ZMS
Parus caeruleus Linnaeus, 1758	2, 5			II				
Parus major Linnaeus, 1758	1–6			II				
Sitta europaea L., 1758	6			II				
Passer domesticus (Linnaeus, 1758)	4							
Passer montanus (Linnaeus, 1758)	1–5			III				
Fringilla coelebs Linnaeus, 1758	1–3, 6			III				
Spinus spinus (Linnaeus, 1758)	1–4			II				S
Chloris chloris (Linnaeus, 1758)	1, 2, 5, 6			II				

1	2	3	4	5	6	7	8	9
Carduelis carduelis (Linnaeus, 1758)	1-6			II				
Acanthis cannabina (Linnaeus, 1758)	1–6			II				
Pyrrhula pyrrhula (Linnaeus, 1758)	5			III				S
Coccothraustes coccothraustes (Linnaeus, 1758)	1			II				
Emberiza citrinella Linnaeus, 1758	1,2,4–6			II				
Emberiza hortulana Linnaeus, 1758	3, 4			III				ZS

Explanation to Table 3

Site name:	IUCN categories	European Red List categories	Bern Convention	Bonn Convention	CITES	Red Data Book of Ukraine categories
1 — Amvrosievka 2 — Bylbasovka 3 — Dokuchaevsk 4 — Novotroitske 5 — Raygorodok 6 — Seversk	NT — near threatened	NT — near threatened, VU — vulnerable	II — Annex II, III — Annex III	I — Annex I, II — Annex II	II — Annex II	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.

is considered declining (category D); 50 species are listed in regional (or “oblast”, referring to one of Ukraine’s 24 primary administrative units) red data books: these include 6 reptile, 6 mammal and 38 bird species.

The results from analyzing 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.

Table 4. Results of the Generalized Linear models for considered variables of habitat features affecting species richness

		Birds		
Variable	Slope	Intercept	G-statistic	P (slope = 0)
D / sqrt (A)	0.647	2.351	4.487	0.034
Slope (mean)	0.130	2.189	4.924	0.026
Terrain wetness index (SD)	0.346	2.611	8.607	0.003
Enhanced vegetation index (SD)	11.524	2.756	3.973	0.046
Brightness (mean)	–1.980	4.549	7.295	0.007
Brightness (SD)	–3.075	3.983	4.064	0.044
Wetness (mean)	7.691	4.110	5.195	0.023
Brightness temperature (mean)	–0.142	7.604	8.587	0.003
	Mammals			
Brightness (SD)	–7.745	3.000	5.241	0.022

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). The traditionally negative view of such sites among ecologists is rapidly changing. The conservation potential of quarry sites has been documented for vascular plants, orthopterans, butterflies, spiders and wild bees (Tropek et al., 2010; Bétard, 2013), but fewer studies concern terrestrial vertebrates (Lameed, Ayodele, 2010). Of particular relevance to the aim of this study, the results showed that the disused quarries today act as refuges for many species of terrestrial vertebrates, some of which have high conservation value. Here, as in other quarry and post-mining sites (Tropek et al., 2010), spontaneous succession proves to be an effective restoration tool that enhances biodiversity and promotes the settlement of specialized and/ or endangered species. In many cases, this restoration strategy can be preferred to technical reclamation, consisting of covering sites by topsoil or overburden, with the consequence of eliminating the original landforms created by quarrying (Bétard, 2013).

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-quarrying sites. Here we have explored simple measures of geodiversity, which provided a time-saving and financially practical way of measuring abiotic environmental heterogeneity of the study units.

Of the shape metrics the ratio of the Maximum Distance to the square root of the area, D / sqrt (A), was positively related to bird species richness. This metric gives an indication of the patch shape ranging from simply-shaped, more compact patches like the Raygorodok quarry (1.52) to elongated and convoluted patches, for instance, the Dokuchaevsk quarry (2.27). Shape may have a critical effect on the ecological roles of patches. As outlined in one of the "form-and-function" ecological principles of shape (Forman, 1998), convoluted forms are effective in enhancing interactions with the surroundings. Longer boundaries in relation to patch interior provide a greater probability of movements across an edge. 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).

The mean slope too was positively related to bird species richness, which may be related to the influences of slope on vegetation composition and structure (Martinuzzi et al., 2009) and it may be as well that in steeper places birds are less affected by disturbance.

A positive relationship with bird species richness was found with the standard deviation (SD) of the Terrain wetness index, which describes the spatial heterogeneity of the potential for water accumulation in the location. Indeed, quarries with large inundated areas alongside with smaller patches of temporary or seasonal water bodies are in general richer in bird species. This notion is supported by the positive relation of the mean wetness to bird species richness and the reverse by the mean brightness (water surfaces have poor reflectance).

The standard deviation (SD) of the enhanced vegetation index echoes the positive relationship with bird species richness found for the SD of the Terrain wetness index: increased spatial heterogeneity of the vegetation cover, ranging from patches of dense vegetation (0.3–0.4) to patches where the values are around zero (usually these are water, ponds and streams), generally favours a richer composition of bird species.

Low spatial heterogeneity of brightness seems to favour species richness of both birds and mammals. In this case increasing spatial heterogeneity may mean there is a considerable portion of patches not only of low reflectance (i. e., primarily wet areas, which encompass several microhabitats etc.), but ones of high reflectance such as bare soil, rock etc., which could be poor for habitation or house specialized species. For instance, horned larks (*Eremophila alpestris*) are common in grasslands, preferring short, sparsely vegetated areas (Beason, 1995). Population density of the species has been demonstrated to be associated with bare ground and brightness was found to positively match the species' preference for low cover and bare soil (Wiens et al., 2008).

Finally, the mean brightness temperature in general negatively impacts bird species richness: "hotter" places have fewer species than "cooler", which could be associated with the availability of water and shading vegetation (Hafez, 1964).

The vast majority of studies conducted on wildlife response to anthropogenic impact have focused on birds in part because birds are rich in species and easily monitored. Because only six quarry sites were examined, sufficient quantitative data was collected precisely for birds, however the relationships between environmental heterogeneity and species richness found for birds may to a certain extent be true for other taxa, for instance amphibians, the presence of which is correlated with that of birds (Spearman correlation coefficient 0.94, $p < 0.05$). Wetlands associated with quarry sites around which many bird species are centered can support amphibian populations that wouldn't otherwise have been present on the site (Myers, Klimstra 1963; Lannoo et al. 2009; Sievers, 2017). The same can relate to the European pond turtle (Fritz, Chiari, 2013). In general, large expanses of open water can become home to a wide range of aquatic and waterside habitats, including a big variety of birds, reptiles and mammals.

Conclusion

Our study confirmed a potential of the post-quarrying landscape for sustaining and conservation of numerous species of terrestrial vertebrates. Spontaneous succession seems to have enhanced biodiversity and promoted the settlement of specialized and/or endangered species.

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 species that colonize exhausted quarries. Comprehensive research in connecting geo- and biodiversity deserves further attention in habitat conservation and restoration strategies in post-quarrying sites.

In the future, long-term monitoring plans should be designed to evaluate the impacts of quarrying 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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