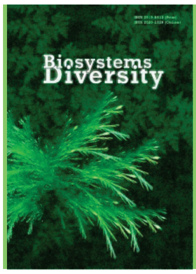

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The main factors and prospects for the restoration of biodiversity in technogenic territories (on the example of the Poltava Mining and Processing Plant)

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Mining activities radically change natural ecosystems, the recovery of which is not possible without the restoration of native or transformed communities of autotrophic and heterotrophic organisms. In order to analyze the success of biodiversity restoration using unified methods, an inventory of higher plant flora and avifauna species in the technogenic territories of the Poltava Mining and Processing Plant was carried out. The dominant species identified in mining dumps, tailings, bypass and drainage canals, urban wastewater treatment and bioengineering facilities and on the PMP territory have been studied in detail. The studies were carried out in the spring-summer period of 2021–2022. The avifauna includes 140 species belonging to 18 orders and 45 families (Passeriformes predominate – 62.0%). 103 species nest on the PMP territory, 32 nomadic and 5 transient species are also registered. The nesting avifauna is dominated by representatives of both native nemoral (16.0%, n = 103) and forest-steppe (13.0%) and tropical (14.0%) avifauna. A significant number of birds belong to limnophiles, which prevail in the territories of the urban wastewater treatment plant (66.7%, n = 30) and tailings (62.5%, n = 24). They are also common in the bypass and drainage canals, where hydro- and hygrophilous phytocenoses have formed, similar to floodplain and real meadows as part of adjacent wetland ecosystems. Among the surrounding natural biogeocenoses, there are no steppe ones with their inherent unique floristic composition, which explains the small number of stepants in the studied flora and campophiles in the avifauna. In recovery successions, general patterns were revealed: biogeocenoses surrounding the technogenic territories of the PMP are the main source of producer diasporas and a variety of consumers, which are so necessary for the restoration of degraded landscapes. Phanerophytes from the genera *Populus*, *Pinus*, *Fraxinus*, *Ulmus*, *Morus*, *Juglans*, etc. are determinants in the sylvacenoses formed on the dumps and territories of the plant. Therefore, dendrophiles characteristic of neighbouring pine and floodplain forests, as well as garden phytocenoses in the private sector territory, dominate in the ornithocomplexes. Nationally rare avifauna includes 5 species, two of which nest. Among the identified bird species, the following nesting species are listed in the Red Book of Ukraine: *Columba oenas*, *Himantopus himantopus*, as well as transient and nomadic species: *Hieraaetus pennatus*, *Haliaeetus allbicilla*, *Milvus migrans*. The success of the natural formation of plant communities, the rich ornithological complex with the participation of rare species, and the location of the PMP territory within the migration routes indicate the expediency of further research into the possibilities of their inclusion in the nature reserve fund with the status of "territory of renaturalization".

Keywords: flora of vascular plants; avifauna; mining; successions; biological diversity; rare species.

Introduction

Technogenic impact causes various types of environmental disturbances, including changes in the habitat, infrastructure facilities, pollution with heavy metals and other pollutants (Sonter et al., 2014). The mining industry, which is a priority for the economic development of the country, has an ambiguous effect on physical processes in nature: it increases erosion, karst and landslide phenomena (Doupe & Lymbery, 2005, Kopiy, 2018), destroys the soil cover (Sonter et al., 2017), affects biodiversity (Butt et al., 2013; Murguia et al., 2016; Harfoot et al., 2018). In world practice, quite often mining operations overlap with areas important for biota conservation (Duran et al., 2013; Reid et al., 2019).

To restore the nature protection functions of technogenic territories, it is planned to reclaim mining dumps through land phytoremediation measures (Ingold & Dooley, 2013; Chećko et al., 2022), the creation of programs for the restoration of vegetation and enrichment of biodiversity, environmental monitoring (Holl, 2002; Bell et al., 2017; Yunanto et al., 2021), etc. Birds play an invaluable role in reforestation and biota resettlement as the most mobile and organized group of animals with a high metabolic rate (Amanah & Yunanto, 2019; Kiere et al., 2021).

On the one hand, the processes of vegetation cover succession depend on the diversity of birds in the environment (Borthwick & Wang, 2015). On the other hand, phytocenoses and their successions determine nesting ornithocenoses: abundance and species composition (Slankard et al., 2018; Koshelev et al., 2020a). Therefore, the analysis of the avifauna is a fairly reliable bioindication method for the restoration of transformed areas that are subject to technogenic impact (Lehikoinen, 2013; Catarino et al., 2016). Given the rather large areas of territories of technogenic origin, in Ukraine (Shapar & Mikheyev, 2018) there is an urgent need to study the features of the formation and patterns of ornithocenoses within such biotopes, as well as develop recommendations for their conservation and management development (Baczyńska et al., 2017; Gavris et al., 2017; Ulyura, 2018).

The PMP is located within the Left Bank of the Dnieper forest-steppe zone of Ukraine, in the valleys of the Dnieper and the lower reaches of the Psel River. The plant was put into operation in 1970. Most of the area of its territory is exposed rock, where the restoration of biota began and is happening from scratch (dumps, quarries, roads, industrial facilities, tailings) or in anthropogenically modified areas (drainage and bypass canals, bioengineering facilities). Restoration in such territories begins with the introduction of seed material of producers and the penetration of consumers and decomposers from neighbouring biocenoses.

The success of such natural succession is associated with the compliance of technogenic territories with the ecological requirements of the biota of nearby landscapes and the possibility of their diasporas or individuals entering these territories. Therefore, in order to analyze the success of biota restoration in the technogenic territories of the PMP, we studied the ornithological complex, represented by consumers of all trophic levels, and also studied the dominant species of the vascular plants flora that form the most typical phytocenoses on the territory of various technogenic sites.

Within the territory of the PMP, the nationally important Dnieper ecological corridor passes, collecting the flow of ornithological migrants along the cascade of water reservoirs (Maltsev et al., 2010). The concentration of the migration flow of the avifauna occurs due to the diversity of territories that are energetically favourable for bird migration: rich in food resources, the presence of convenient places for rest and landscape landmarks (Ilyukha, 2014). The distribution of species, their abundance and relative stability in the Dnieper ecological corridor depend, first of all, on the possibility of unhindered migration of individuals of populations between the structural elements of the ecosystem (Gavrilyuk et al., 2016; Gavrilyuk et al., 2022).

Therefore, the purpose of our research is to study the current state of the avifauna, which is formed under the conditions of specific phytocenoses on technogenically degraded territories in order to analyze the factors and prospects for the restoration of species biodiversity as a result of the recovery of disturbed ecosystems of the PMP.

Materials and methods

Field studies were carried out in the spring-summer periods of 2021–2022 at various mine technogenic zones, the territory of which is located in the southern part of the Poltava region (Horishni Plavni city) (Fig. 1a, 1m). The PMP activity is based on a full technological cycle: from ore mining to the production of iron pellets. To ensure the production process, the PMP has a processing complex, which includes crushing and enrichment plants and a pellet manufacturing facility too. Open pit mining is carried out using an explosive method of ore mining. This method causes a number of environmental risks: emissions of dust, heavy metals, explosive products into the atmosphere, changes in the hydrological regime, discharge of wastewater, pollution of the upper part of the soil cover, changes in the natural chemical regime of waters, etc. All this affects the natural process of geo-ecological self-regulation of the natural environment of Poltava region and can lead to rapid and irreversible degradation.

The PMP territory is located near the Horishni Plavni city and is surrounded by natural, natural-anthropogenic and anthropogenic biogeocenoses of pine and floodplain forests, saline and floodplain meadows, as well as agricultural fields, private gardens and green spaces. The following technogenic landscapes dominate on the PMP territory: iron ore processing plant, mining quarry (Fig. 1a), waste rock dumps (Fig. 1b, 1c), bioengineering facilities (Fig. 1d), tailings (sumps for storage ore processing waste (Fig. 1e, 1f), artificial reservoirs on the PMP territory (Fig. 1g), bypass (Fig. 1h) and drainage (Fig. 1i, 1j) canals, urban wastewater treatment plants (Fig. 1k, 1l).

Fig. 1. Schematic location of the studied territories: *a* – quarry; *b*, *c* – waste rock dumps of PMP; *d* – bioengineering facilities; *e*, *f* – tailing ponds; *g* – technogenic reservoirs on the PMP territory; *h* – sections of the bypass canal; *i*, *j* – sections of the drainage canal around the tailings; *k*, *l* – urban treatment plant in Horishni Plavni city; *m* – PMP on the world map

Almost all of these technogenic biogeocenoses are formed in areas completely or partially devoid of soil cover. The exceptions are the bypass and drainage canals and bioengineering facilities created in areas with a typical soil cover. The 17 km long drainage canal is located around the tailings of the PMP and is designed to intercept and reduce the flow of seepage water, as well as prevent it from entering groundwater. In case of excessive discharge of seepage waters, the bypass canal bordering the oxbow lakes of the Suhyi Kobelyachok River and floodplain meadows, intercepts excess water, protecting the surrounding areas from flooding and associated pollution. Bioengineering facilities for additional purification of clarified waters of tailings and a cascade of bioplateaux with a dam, which filters and purifies rain and melt water, gives the PMP the opportunity not to discharge water into surface water bodies without treatment (Table 1).

To monitor the species diversity of birds, we established permanent routes in different parts of the PMP territory. Route-point counts of birds were carried out in the spring-summer periods (from March 1 to August 30 2021–2022) five or six times a season. In total, more than 120 km have been covered. The experiment was carried out in compliance with the norms of bioethics, in accordance with the provisions of the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes. The similarity of bird distribution in the studied areas was calculated using the Sorensen formula (species similarity index): $Cs = 2j / (a + b)$, where j is the number of species common to both groups of nesting birds, a is the number of species from first group, b is the number of species from second group.

In accordance with the classification of Potesh (2009) and based on original observations, each species was assigned one of three habitation status: nesting (n) – species nesting in the study area; nomadic (no) – a species whose nesting zones are not in the study area, but systematically appear here in the summer; transient (t) – a species that does not nest nearby, but constantly uses the territory for flights and stops during seasonal migrations.

The fauna communities were described according to the classification of Belyk (2000). We used the guide to birds of Ukraine to identify birds (Fesenko & Bokotey, 2002). The taxonomy of birds is presented according to Fesenko (2018). Only author’s photos are used in the work, except for those signed on the figures.

Results

The total list of birds found by us includes 140 species that nest on the territory or which visit in the reproductive period or during migrations. They belong to 18 orders and 45 families (Table 2).

Table 1
A brief description of technogenic zones of PMP

No.	Types of technogenic territories	A brief description
1	Active mining quarry	Mining enterprise for the extraction of iron ore by an open method (911.9 ha)
2	Iron ore processing plant	The system of engineering and administrative buildings, including a crushing and enrichment plant (47.8 ha)
3	Tailings	Settling tanks for storage of ore processing waste. The total area of tailings base is 1,400 ha
4	Dumps of gangue rocks	An embankment on the earthen surface from waste rocks obtained during the development of mineral deposits, tailings of processing plants. The total area of the western external dump is 804.5 ha (including 54.3 ha covered with forest). Trees are about 40 years old. The area of the eastern outer dump is 832.8 ha
5	Drainage canal	A ditch 3–5 m wide, into which water from the tailings is supplied through special pipes. Designed to intercept and reduce the flow of seepage water and prevent it from entering groundwater, it is located around the tailing dump of the enterprise with a length of 17.188 km
6	Bypass canal	The canal, bordering on one side with the drainage channel, on the other with the oxbows of the Suhyi Kobelyachok River and meadows. Created to intercept excess water and protect surrounding areas from flooding and thus from pollution. Canal length – 9.61 km
7	Bioengineering facilities	Energy-efficient engineering structures for wastewater treatment, developed on the basis of the properties of natural wetlands, in which the processes of microbial transformation and phytoremediation of pollution take place. The capacity is 72 thousand m^3 of water per day, the area is 18 ha
8	Artificial reservoirs on the PMP territory	Small (0.5–1.0 ha) artificial depressions in the earth's surface filled with water
9	Urban wastewater treatment plants	Filtration fields of urban wastewater treatment plants, where Horishni Plavni city wastewater is treated. The area is 5–6 ha

Table 2
Species diversity of PMP technogenic territories

Bird species	Drainage canal	Mining dumps	Bypass canal	Tailings	Bioengineering facilities	Urban waste–water treatment plants	PMP territory	Fauna types*	Ecol. group*
	habitation status*								
Podiceps ruficollis (Pallas, 1764)	no	–	n	–	–	–	–	tr	l
P. cristatus (Linnaeus, 1758)	–	–	n	–	–	–	–	tr	l
Phalacrocorax carbo (Linnaeus, 1758)	no	–	no	no	–	–	–	tr	l
Botaurus stellaris (Linnaeus, 1758)	–	–	n	–	–	–	–	fr	l
Ixobrychus minutus (Linnaeus, 1758)	n	–	n	–	–	–	–	tr	l
Nycticorax nycticorax (Linnaeus, 1758)	no	–	no	–	–	–	–	tr	l
Egretta alba (Linnaeus, 1758)	no	no	no	no	no	no	–	tr	l
Ardea cinerea (Linnaeus, 1758)	no	–	no	no	no	no	–	tr	l
A. purpurea (Linnaeus, 1766)	–	–	no	–	–	–	–	tr	l
Ciconia ciconia (Linnaeus, 1758	no	–	no	no	no	no	–	fs	d
Anser anser (Linnaeus, 1758)	–	–	no	no	–	–	–	fr	l
Cygnus olor (Gmelin, 1789)	–	–	no	–	–	–	–	fr	l
Tadorna ferruginea (Pallas, 1764)	–	–	no	–	–	–	–	fr	l
T. tadorna (Linnaeus, 1758)	–	–	no	–	–	–	–	fr	l
Anas platyrhynchos Linnaeus, 1758	n	–	n	no	–	–	–	br	l
A. querquedula Linnaeus, 1758	no	–	n	–	–	–	–	ap	l
Aythya ferina (Linnaeus, 1758)	–	–	no	–	–	–	–	fr	l
Bucephala clangula (Linnaeus, 1758)	–	–	no	–	–	no	–	br	l
Milvus migrans (Boddaert, 1783)	no	–	no	–	–	–	–	af (tr)	d
Circus aeruginosus (Linnaeus, 1758)	no	–	n	–	–	no	–	fr	l
Accipiter gentilis (Linnaeus, 1758)	–	no	no	–	–	–	no	an	d
A. nisus (Linnaeus, 1758)	–	no	no	–	–	–	no	an	d
Buteo buteo (Linnaeus, 1758)	no	no	no	–	–	–	–	af	d
Hieraaetus pennatus (Gmelin, 1788)	–	no	no	–	–	–	–	fs	d
Aquila pomarina Brehm, 1831	–	–	t	–	–	–	–	tr	d
A. heliaca Savigny, 1809	–	t	t	–	–	–	–	fs	d
Haliaeetus allbicilla (Linnaeus, 1758)	–	t	t	–	–	–	–	af	d
Falco vespertinus Linnaeus, 1758	–	no		–	–	–	–	fs	d

Bird species	Drainage canal	Mining dumps	Bypass canal	Tailings	Bioengineering facilities	Urban waste–water treatment plants	PMP territory	Fauna types*	Ecol. group*
	habitation status*								
F. tinnunculus Linnaeus, 1758	no	n	no	–	–	–	n	tr	s
Perdix perdix (Linnaeus, 1758)	–	n		–	–	–	–	fs	d
Coturnix coturnix (Linnaeus, 1758)	–	–	n	–	–	–	–	tr	c
Phasianus colchicus Linnaeus, 1758	–	n	n	–	–	–	–	tr	d
Grus grus (Linnaeus, 1758)	–	–	t	–	–	–	–	br	l
Rallus aquaticus (Linnaeus, 1758)	–	–	n	–	–	–	–	fr	l
Porzana porzana (Linnaeus, 1758)	no	–	n	–	–	–	–	ap	l
Crex crex (Linnaeus, 1758)	–	–	n	–	–	–	–	ap	c
Gallinula chloropus (Linnaeus, 1758)	n	–	n	–	–	n	–	tr	l
Fulica atra Linnaeus, 1758	–	–	n	–	–	n	–	tr	l
Charadrius dubius (Scopoli, 1786)	–	–	–	–	–	n	–	tr	l
Vanellus vanellus (Linnaeus, 1758)	–	–	–	–	–	n	–	fr	l
Himantopus himantopus (Linnaeus, 1758)	–	–	–	–	–	n	–	tr	l
Haematopus ostralegus Linnaeus, 1758	–	–	no	–	no	–	–	tr	l
Tringa ochropus Linnaeus, 1758	–	–	–	–	–	no	–	br	l
T. glareola Linnaeus, 1758	–	–	–	–	–	no	–	br	l
T. nebularia (Gunnerus, 1767)	–	–	no	–	–	–	–	br	l
T. totanus (Linnaeus, 1758)	–	–	n	–	–	n	–	fr	l
T. stagnatilis (Bechstein, 1803)	–	–	no	–	–	–	–	fr	l
Actitis hypoleucos (Linnaeus, 1758)	–	–	no	no	–	–	–	ap	l
Philomachus pugnax (Linnaeus, 1758)	–	–	no	no	no	no	–	br	l
Limosa limosa (Linnaeus, 1758)	–	–	no	–	–	–	–	fr	l
Larus ichthyaetus (Pallas, 1773)	–	–	–	no	–	–	–	fr	l
L. ridibundus (Linnaeus, 1766)	no	–	no	no	–	no	–	br	l
L. cachinnans Pallas,1811	no	–	no	no	–	no	–	fr	l
L. canus Linnaeus, 1758	–	–	no	no	–		–	br	l
Chlidonias niger (Linnaeus, 1758)	–	–	n	no	–	no	–	br	l
Sterna hirundo Linnaeus, 1758	–	–	no	no	–	–	–	br	l
S. albifrons Pallas, 1764	–	–	no	no	–	–	–	tr	l
Columba palumbus Linnaeus, 1758	n	n	n	–	–	–	n	fs	d
C. oenas Linnaeus, 1758	–	–	n	–	–	–	–	fs	d
C. livia Gmelin, 1789	–	–	–	–	–	–	n	dm	s
Streptopelia decaocto (Frivaldszky, 1838)	–	n	–	–	–	–	n	tr	d
S. turtur (Linnaeus, 1758)	–	n	n	–	–	–		fs	d
Cuculus canorus Linnaeus, 1758	n	n	n	no	no	no	no	tr	d
Asio otus (Linnaeus, 1758)	–	n	n	–	–	–	n	af	d
Caprimulgus europaeus Linnaeus, 1758	–	n	–	–	–	–	–	fs	d
Apus apus (Linnaeus, 1758)	no	no	no	–	–	–	n	dm	s
Alcedo atthis (Linnaeus, 1758)	no	–	n	–	–	–	–	tr	l
Merops apiaster Linnaeus, 1758	–	no	–	n	–	–	–	dm	s
Upupa epops Linnaeus, 1758	no	no	no	–	–	–	–	tr	s
Jynx torquilla Linnaeus, 1758	–	n	no	–	–	–	n	an	d
Picus canus (Gmelin, 1788)	–	no	no	–	–		n	an	d
Dendrocopos major (Linnaeus, 1758)	–	n	no	–	–	–	n	an	d
D. syriacus (Hemprich & Ehrenberg, 1833)	–	n	no	–	–	–	n	sM	d
D. minor (Linnaeus, 1758)	–		no	–	–	–	n	an	d
Riparia riparia (Linnaeus, 1758)	no	no	no	n	–	–	no	dm	s
Hirundo rustica (Linnaeus, 1758)	no	no	no	–	–	–	n	dm	s
Delichon urbica (Linnaeus, 1758)	no	no	no	–	–	–	n	dm	s
Galerida cristata (Linnaeus, 1758)	–	n	no	n	–	–	n	ds	c
Lullula arborea (Linnaeus, 1758)	–	n	–	–	–	–	–	fs	c
Alauda arvensis Linnaeus, 1758	–	n	–	–	–	–	–	ds	c
Anthus campestris (Linnaeus, 1758)	–	n	no	n	–	–	–	ds	c
A. trivialis (Linnaeus, 1758)	–	n	–	–	–	–	–	ds	c
Motacilla flava Linnaeus, 1758	n	n	n	n	n	n	–	br	c(l)
M. citreola Pallas, 1776	–	–	n	–	no	–	–	br	l
M. alba Linnaeus, 1758	n	n	n	n	n	n	n	br	l
Lanius collurio Linnaeus, 1758	n	n	n	–	n	–	–	fs	d
L. minor Gmelin, 1788	–	–	n	–	–	–	–	fs	d
Oriolus oriolus (Linnaeus, 1758)	–	n	–	–	–	–	n	nm	d
Sturnus vulgaris Linnaeus, 1758	no	n	n	no	no	no	n	dm	s
Garrulus glandarius (Linnaeus, 1758)	–	n	n	–	–	–	n	an	d
Pica pica (Linnaeus, 1758)	–	n	–	–	n	–	n	af	d
Corvus monedula Linnaeus, 1758	–	n	n	–	–	–	n	dm	s
C. cornix Linnaeus, 1758	no	n	n	–	n	no	n	fs	d
C. corax Linnaeus, 1758	–	n	–	–	–	–	n	br	s
Locustella luscinioides (Savi, 1824)	–	–	n	–	n	–	–	fr	l
Acrocephalus schoenobaenus (Linnaeus, 1758)	–	–	n	–	–	–	–	ap	l
A. palustris (Bechstein, 1798)	n	n	n	–	n	n	n	ap	l
A. scirpaceus (Hermann, 1804)	n	–	n	–	n	–	–	fr	l
A. arundinaceus (Linnaeus, 1758)	n	–	n	–	n	n	n	fr	l
Sylvia nisoria (Bechstein, 1795)	n	n	n	–	–	–	–	sM	d
S. atricapilla (Linnaeus, 1758)	no	n	–	–	–	–	n	nm	d
S. borin (Boddaert, 1783)	–	–	n	–	n	n	–	nm	d
S. communis (Latham, 1787)	n	n	n	–	–	–	n	sM	d

Bird species	Drainage canal	Mining dumps	Bypass canal	Tail-ings	Bioengineering facilities	Urban waste–water treatment plants	PMP territory	Fauna types*	Ecol. group*
	habitation status*								
S. curruca (Linnaeus, 1758)	n	n	n	–	n	–	n	nm	d
Phylloscopus trochilus (Linnaeus, 1758)	–	t	–	–	–	–	t	br	d
Ph. collybita (Vieillot, 1817)	n	n	n	–	–	n	n	nm	d
Ficedula albicollis (Temminck, 1815)	–	n	–	–	–	–	n	nm	d
Muscicapa striata (Pallas, 1764)	–	n	–	–	–	–	n	nm	d
Saxicola rubetra (Linnaeus, 1758)	–	n	n	n	n	–	–	ap	c
S. torquata (Linnaeus, 1758)	–	–	n	–	–	–	–	tr	c
Oenanthe oenanthe (Linnaeus, 1758)	–	n	–	–	–	–	–	dm	s
Phoenicurus phoenicurus (Linnaeus, 1758)	–	n	–	–	–	–	–	nm	d
Ph. ochruros (S.G. Gmelin, 1774)	–	n	–	–	–	–	n	dm	s
Erithacus rubecula (Linnaeus, 1758)	–	n	–	–	–	–	–	nm	d
Luscinia luscinia (Linnaeus, 1758)	n	n	n	–	n	–	–	nm	d
L. svecica (Linnaeus, 1758)	n	n	n	–	n	n	n	ap	l
Turdus pilaris Linnaeus, 1758	–	no	n	–	–	no	n	br	d
T. merula Linnaeus, 1758	no	n	n	–	–	–	n	nm	d
T. philomelos Brehm, 1831	no	n	n	–	–	–	n	nm	d
T. viscivorus Linnaeus, 1758	–	–	n	–	–	–	–	nm	d
Panurus biarmicus (Linnaeus, 1758)	no	–	n	–	n	–	–	fr	l
Aegithalos caudatus (Linnaeus, 1758)	–	no	no	–	–	–	–	an	d
Remiz pendulinus (Linnaeus, 1758)	n	–	n	–	n	–	–	ap	c
Parus palustris Linnaeus, 1758	no	n	no	–	–	–	n	an	d
P. caeruleus Linnaeus, 1758	no	n	no	–	–	–	n	nm	d
P. major Linnaeus, 1758	no	n	no	–	–	–	n	nm	d
Sitta europaea Linnaeus, 1758	–	n	no	–	–	–	n	an	d
Certhia familiaris Linnaeus, 1758	–	n	no	–	–	–	n	an	d
Passer domesticus (Linnaeus, 1758)	–	–	–	–	–	–	n	dm	s
P. montanus (Linnaeus, 1758)	no	n	no	–	–	no	n	dm	s
Fringilla coelebs Linnaeus, 1758	no	n	no	–	–	–	n	nm	d
Chloris chloris (Linnaeus, 1758)	no	n	n	–	–	–	n	fs	d
Carduelis carduelis (Linnaeus, 1758)	–	n	n	–	–	–	n	fs	d
Acanthis cannabina (Linnaeus, 1758)	–	n	n	–	–	–	n	fs	d
Carpodacus erythrinus (Pallas, 1770)	–	–	n	–	–	–	–	br	d
Coccothraustes coccothraustes (Linnaeus, 1758)	no	n	n	–	–	–	n	an	d
Emberiza calandra Linnaeus, 1758	–	n	no	–	–	–	–	ds	c
E. citrinella Linnaeus, 1758	–	n	n	–	–	–	–	fs	d
E. schoeniclus (Linnaeus, 1758)	–	–	n	–	n	–	–	ap	l
E. hortulana Linnaeus, 1758	–	–	n	–	–	n	–	fs	d

Note: * – habitation status: nesting (n), nomadic (no), transient (t); types of fauna: nemoral (nm), ancient-nemoral (an), forest-steppe (fs), tropical (tr), desert-mountain (dm), desert-steppe (ds), ancient-forest (af), firth/estuary (fr), boreal (br), subMediterranean (sM) and alluviophilic (ap); ecological groups: dendrophiles (d), sclerophylls (s), campophiles (c), limnophiles (l).

Analysis of the avifauna in different technogenic phytocenoses. The largest technogenically altered areas of the mining and processing complex are occupied by waste rock dumps, the vegetation cover of which is formed by a complex of tree-shrub and herbaceous plant species that have colonized these substrates devoid of soil cover due to the spread of their seeds with the help of anemo- and ornithochory from neighboring pine and floodplain forests. These are typical woody forest species – representatives of the autochthonous flora: *Pinus sylvestris* L., *Populus nigra* L., *P. alba* L., *P. tremula* L., *Betula pendula* Roth., *Quercus robur* L., *Acer tataricum* L., *Fraxinus excelsior* L., *Sorbus aucuparia* L., *Ulmus minor* Mill., *Rosa corymbifera* Borkh., *Ligustrum vulgare* L., *Rhamnus cathartica* L.

Sparse or dense sylvacenoses are formed on the flat areas of dumps and slopes up to 30° with the dominance of *Pinus sylvestris*, *Betula pendula* or *Populus* spp. On the edges and lawns, introduced and cultivated species are widespread, which are grown in the adjacent household plots: *Pyrus communis* L., *Malus domestica* (Borkh.) Borkh., *Elaeagnus angustifolia* L., *Morus alba* L., *Robinia pseudoacacia* L., *Acer negundo* L., *Prunus armeniaca* L., *Ailanthus altissima* (Mill.) Swingle, *Prunus cerasifera* Ehrh., *Hippophae rhamnoides* L., *Aesculus hippocastanum* L., *Parthenocissus quincusfolia* L., *Aronia melanocarpa* (Michx.) Elliott. All types of woody ornithochore plants entered these technogenic landscapes thanks to birds: their fruits and seeds are the food for most adult and young birds in the late summer, autumn and winter seasons.

Significant areas of dumps are devoid of trees and shrubs; sparse herbaceous phytocenoses are usually formed here with a predominance of weeds, more typical for agrocenoses: *Artemisia absinthium* L., *Ambrosia artemisiifolia* L., *Cichorium intybus* L., *Melilotus officinalis* (L.) Pall., *Daucus carota* L., *Bellis annua* L., *Echium vulgare* L. There are also typical representatives of meadow and steppe natural phytocenoses: *Calamagrostis epigejos* (L.) Roth, *Poa compressa* L., *Medicago falcata* L., *Oenothera biennis* L., *Centaurea reichenbachii* DC., *Sedum acre* L., *Phragmites australis* (Cav.) Trin. ex Steud, *Tanacetum vulgare* L., *Tussilago farfara* L., *Helichrysum arenarium* (L.) Moench, *Achillea millefolium* L., *Hypericum perforatum* L., *Thymus pulegioides* subsp. *Pannonicus* (All.) Kerguelen, *Chondrilla juncea* L., *Hieracium virosum* Pall. and others. Woody and herbaceous anemochores are brought to dumps by currents that carry their fruits and seeds. In different seasons of the year, these generative organs of plants are nutritious food for many bird species from the orders: Galliformes, Columbiformes, Passeriformes.

Dumps that have not been replenished with rock for more than 30 years, as a rule, are completely covered with grassy vegetation. The total cover on flat areas is 70–90%, on slopes – 30–60%. Such technogenic biotopes are inhabited by birds of both open space and dendrophiles. At the initiative of the environmental service of the PMP, ten years ago, artificial nests for small Passeriformes were placed on the eastern dumps, in which secondary hollow-nesters now nest. 75 species of birds were registered in different parts of the dumps, including 57 nesting and 15 nomadic (in search of food or rest), three species are transient. During the nesting period, Passeriformes predominate in the ornithocomplex of dumps – 60.0% (n = 57).

In open areas of dumps covered with psammophytes, low sparse stands, and single specimens of bushes, the ornithocenosis is dominated by: *Lanius collurio* (Fig. 2a, 2b), *Motacilla alba*, *Sylvia communis*, *Galerida cristata*, *Oenanthe oenanthe*, and *Saxicola rubetra*. Less common are specimens of *Sylvia nisoria*, *S. curruca*, *Acanthis cannabina*, *Muscicapa striata*. Sometimes nesting in small numbers are *Carduelis carduelis*, *Coccothraustes coccothraustes*, *Emberiza calandra*, *Anthus campestris* and *Anthus trivialis*. A rare nesting bird is *Caprimulgus europaeus*. The avifauna of the overgrown dumps is based on tree and shrub loving species of birds from the surrounding landscapes. In particular, *Chloris chloris* (Fig. 2d), *Fringilla coelebs* (Fig. 2c), *Turdus merula* (Fig. 2e) dominate in areas of closed forest phytocenoses, *Turdus philomelos* (Fig. 2f), *Erithacus rubecula*, *Phylloscopus collybita*, *Sylvia atricapilla*. *Ficedula albicollis*, *Parus major* and *Cyanistes caeruleus* nest in the few hollows of *Dendrocopos*, artificial nests and cavities between the stones of dumps, and *Phoenicurus ochruros* and *Ph. phoenicurus* nest much less frequently. *Luscinia luscinia* occurs near windfall stands. Corvidae nest on separate tall trees: *Corvus cornix* and *C. corax*, sometimes *Garrulus glandarius*, *Pica pica* too. On dumps bordering on wetland biotopes, the following species join the ornithocomplexes: *Acrocephalus palustris* and *Luscinia svecica*. *Corvus corax*, *C. cornix*, *Falco tinnunculus* and others nest in areas of dumps where there are power supply poles (Fig. 3). Waste rock dumps in the vicinity of the quarry are not suitable for most bird specis. *Oenanthe oenanthe* and *Galerida cristata* can sometimes nest in such areas. Birds of prey are hunting on reptiles and mouse-like rodents, which are found in small numbers.

Fig. 2. Nesting of birds on overgrown dumps: *a* – nest of *Lanius collurio*; *b* – female *Lanius collurio*; *c* – nesting of *Fringílla coélebs* on the sycamore maple; *d* – a nest with *Carduelis chloris* chicks on the undergrowth of a pear; *e* – a nest of *Turdus merula* on a poplar; *f* – *T. philomelos* nest on an elm

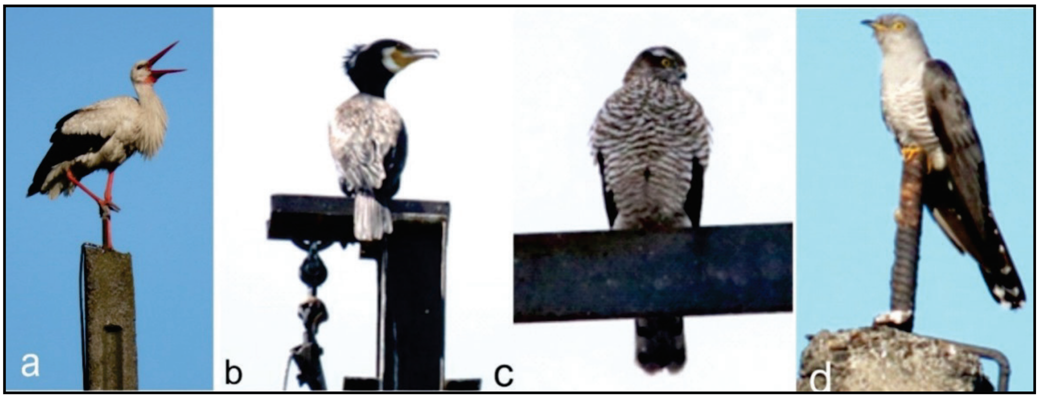

Fig. 3. The use of technogenic structures for feeding by various birds on the PMP territory:
a – *Ciconia ciconia*, *b* – *Phalacrocorax carbo*, *c* – *Accipiter nisus* (photo by Y. P. Mamedova), *d* – *Cuculus canorus*

Wetland biotopes of technogenic origin include tailing ponds, drainage and bypass canals, bioengineering facilities and urban wastewater treatment plants. These biotopes function as ecological corridors during bird migration, as they provide a safe resting and feeding area for both nesting and nomadic species. On the PMP territory there are overgrown tailings, inhabited by water birds that prefer open spaces. A total of 124 bird species were recorded in these areas, including 69 nesting ones.

During the construction of the canals, the soil cover was completely disturbed, so the formation of vegetation occurred thanks to a seed bank preserved in the soil and plant species that came here from the nearby natural floodplain phytocenoses. The total width of shoreline aquatic phytocenoses, including the canal water surface, ranges from 30 to 150 m. Typical hydrophytocenoses have formed in the canal. These are associations of higher aquatic plants, among which species of the genera *Lemna* and *Potamogeton dominate*, as well as *Spirodela polyrhiza* (L.) Schleid., *Nuphar lutea* (L.) Sm., *Ranunculus aquatilis* L. and others.

Species of the genus *Carex*, *Phragmites australis* L., *Typha angustifolia* L., *Scirpus sylvaticus* L., *Sparganium emersum* Rehmann, *Alisma plantago-aquatica* L. and other waterlogged biotopes are common in the shore zone. Since the bypass canal borders natural boreal and nemoral sylvacenoses and horticultural phytocenoses, phanerophytes from these ecosystems are found on its banks. These are individual trees and shrubs that do not form continuous thickets: *Betula pendula*, *Pinus sylvestris*, *Populus* spp., *Morus alba*, *Salix* spp., *Ulmus minor*, *Elaeagnus angustifolia*, *Acer negundo*, *Sambucus nigra*, *Crataegus rhipidiphylla* Gand., *Rubus caesius* Thunb., *Cornus sanguinea* Hemsl., *Prunus spinosa* L., *Rhus coriaria* L. and others.

The grass cover is formed by typical meadow, psammophyte and steppe plant species, as well as ruderal and roadside weeds: *Pilosella officinarum* Vaill., *Pilosella echioides* subsp. *echioides* (Lumn.) F. W. Schultz & Sch. Bip., *Hypericum perforatum*, *Trifolium pratense* L., *Achillea millefolium*, *Humulus lupulus* L., *Centaurea jacea* L., *Linaria vulgaris* Mill., *Medicago falcata*, *Lotus corniculatus* L., *Lathyrus tuberosus* L., *Chondrilla juncea*, *Gypsophila paniculata* L., *Anthemis ruthenica* M. Bieb., *Sedum acre*, *Helichrysum arenarium*, *Epilobium hirsutum* L., *Asparagus officinalis* L., *Dactylis glomerata* L., *Poa pratensis* L., *P. angustifolia* L., *Calamagrostis epigeios* (L.) Roth, *Bromus inermis* Leyss., *B. squarrosus* L., *Carex praecox* Schreb., *C. colchica* J. Gay, *Koeleria sabuletorum* DC., *Festuca rupicola* Heuff.

The ruderal fraction of the flora is represented mainly by perennial weeds: *Lactuca tatarica* C. A. Mey., *Artemisia vulgaris* L., *A. absinthium*, *Tanacetum vulgare*, *Melandrium album* Poir., *Cichorium intybus*, *Cirsium arvense* (L.) Scop., *Sonchus asper* (L.) Hill. Annual and biennial weeds include *Melilotus officinalis*, *M. albus* Medik., *Bellis annua*, *Daucus carota*, *Lactuca serriola* L., *Oenothera biennis*, *Consolida regalis* L., *Erigeron canadensis* L., *Cynoglossum officinale* L., *Ambrosia artemisiifolia*, *Onopordum acanthium* L., *Carduus acanthoides* L., *Setaria pumila* Roem. & Schult., *S. viridis* (L.) P. Beauv., *Verbascum lychnitis* L., *V. densiflorum* Bertol., *Papaver rhoeas* L.

Birds colonize the bypass canal most massively during the reproductive period: 59 species nest here and 50 species feed or rest. Fewer birds are found on the drainage canal, with 18 species nesting and 33 feeding or resting. The drainage canal has a water surface width of 3 to 5 m. Its steep banks are covered with shoreline aquatic vegetation dominated by *Phragmites australis*. In a row, on upland areas, meadow phytocenoses are located in the form of strips of different widths. The canal borders on one side with the bulk dam of the tailings and on the other side, it has its own dam covered with trees and shrubs.

The dominant species among the nesting birds of the drainage and bypass canals are *Acrocephalus arundinaceus*, *Luscinia svecica*, *Remiz pendulinus* and *Anas platyrhynchos*. It is important to note that two subspecies of *Luscinia svecica* occur in different technogenic sites: *L. svecica volgae* (Fig. 4a) and *L. svecica cyanecula* (Fig. 4b). Most species of Fringillidae and Passeridae feed on the seeds of common weed species. In the range of bypass and drainage canals, *Gallinula chloropus*, *Anas querquedula*, *Rallus aquaticus*, *Porzana porzana*, *Fulica atra*, *Botaurus stellaris* and *Ixobrychus minutus* are found. Their nesting is due to the presence of appropriate coastal aquatic vegetation – *Phragmites australis* and other species, where birds hide their nests.

Fig. 4. Species diversity of birds of bypass canals:
a – *Luscinia svecica volgae*, *b* – *Luscinia svecica cyanecula*, *c* – *Podiceps cristatus*, *d* – *P. ruficollis e* – *Nycticorax nycticorax* feeds on the shallow water, *f* – *Tringa glareola* feeds on sections of the canal

The species *Motacilla alba* is numerous, nesting in shoreline niches and feeding on canals. *Chlidonias niger*, *Podiceps cristatus* (Fig. 4c) and *Podiceps ruficollis* (Fig. 4d) settle in the open water areas of the bypass canal in the presence of hydrophilic vegetation. The drainage and bypass canals are often visited for feeding and rest by *Larus michahellis* and *L. ridibundus*, *Ardea alba* and *A. cinerea*, *Nycticorax nycticorax* (Fig. 4e), *Sterna albifrons* and *S. hirundo*, *Phalacrocorax carbo*, various species of hydrophilic and other avifauna (Fig. 4f). We observed how *Ciconia ciconia* and different species of the genus *Ardea* hunted lizards and rodents among the grasses. In swampy areas between the drainage and bypass canals near the Sukhiy Kobelyachok River *Circus aeruginosus* can be found and flocks of Charadrii spp. and Anatinae spp. feed. The main hosts of *Cuculus canorus* chicks are *Acrocephalus arundinaceus*, *Motacilla alba* and *Curruca communis*. To search for potential hosts, *Cuculus canorus* uses various man-made structures: poles, wires, towers, etc. *Lanius collurio*, *Remiz pendulinus* (Fig. 5a), *Sylvia nisoria* (Fig. 5e, 5f), *S. curruca*, *Fringilla coelebs*, *Chloris chloris*, *Oriolus oriolus*, *Columba palumbus* nest on trees and shrubs near the canals. (Fig. 5c, 5d). Asio otus breeds in *Pica pica* or *Corvus cornix* nests (Fig. 5b).

Crex crex, *Perdix perdix*, *Coturnix coturnix*, *Phasianus colchicus* nest in small numbers in the border areas between the drainage and bypass canals. The advantage for breeding ground-nesting birds in these areas is the absence of human disturbance due to the constant protection of the PMP service, as well as the absence of domestic or feral dogs and cats. In this area, *Columba oenas* nests in power pylons. The population of this rare species included in the Red Data Book of Ukraine (Akimov, 2009) was 14 pairs (Fig. 6a–d). It is important to note that the birds chose areas bordering fields and which are closed to visitors. During the migration period in the zone between the bypass canal and the Sukhiy Kobelyachok River *Grus grus* can stop to rest.

The local reservoirs of the tailing dump attract migrating and transiting waterfowl and near-water birds mainly for recreation. The soil cover is completely absent here, and the formation of the solid surface of the tailings occurs by pumping the pulp, which carries small parts of the waste rock, so there is no vegetation here.

Fig. 5. Nesting of birds on bushes and trees near the drainage canal: *a* – *Remiz pendulinus* builds a nest on an olive tree, *b* – *Asio otus* chicks in an old *Corvus cornix* nest, *c*, *d* – *Columba palumbus* nesting on trees near the drainage canal, *e* – male *Sylvia nisoria* squatting, *f* – *S. nisoria* nest with chicks

In different periods, seven nesting and 17 nomadic bird species were found in this technogenic territory, arriving for hunting or rest. Concentrations of *Larus cachinnans*, *L. argentatus*, and *Chroicocephalus ridibundus* are formed in the reservoirs of the tailings. Flocks of other wetland birds are recorded: *Phalacrocorax carbo*, *Anser anser*, *A. platyrhynchos*, *A. querquedula* and others. During seasonal migrations, waders fly in *Philomachus pugnax*, *Tringa glareola*, *T. ochropus*, *T. totanus*, *Actitis hypoleucos*. During the nesting season, *Ardea cinerea* and *A. alba* visit the tailings. Occasionally *Tringa nebularia*, *Limosa limosa*, *Haematopus ostralegus* and *Larus ichthyaetus* are seen. Among birds of prey, *Accipiter nisus*, *A. gentilis*, *Buteo buteo*, *Milvus migrans*, *Haliaeetus allbicilla*, *Hieraaetus pennatus* and others visit the tailing dump in search of food.

Drier areas of the tailings surface are sown with winter wheat, which contributes to the turfing of the substrate and prevents it from dispersing, which is especially dangerous in snowless winters. Here, during the growing season, transient birds stop and *Alauda arvensis*, *Motacilla flava*, *Saxicola rubetra* nest. During the periodic treatment of the tailing dump from dry rock, vertical walls up to 1.5 m high are formed. A colony of *Riparia riparia* manages to settle and hatch chicks in them (Fig. 7a, 7b). Single nests of *Merops apiaster* and *Apus apus* have been recorded. Employees of the PMP carry out further work on treatment up the tailing dump only after the end of the nesting period of these birds. Numerous flocks of *Riparia riparia* feed above the water surface of the drainage and bypass canals.

Fig. 6. Nesting of *Columba oenas* in power line poles on the PMP territory:
a – young *Columba oenas* in 2022, *b* – reproduction in the cavities of the pillars, *c*, *d* – adult birds near the nest

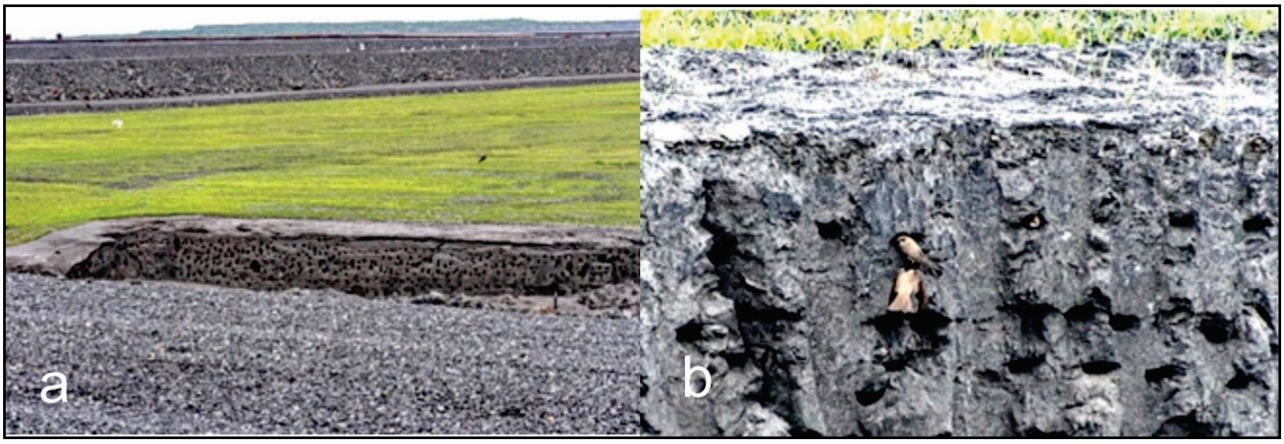

Fig. 7. Colony of *Riparia riparia* on the tailings: *a* – general view; *b* – a pair of *Riparia riparia* birds near the nest (photo by M. O. Filatova)

There is almost no soil cover on the territory of the bioengineering facilities, so the vegetation cover here is formed by species whose seeds are carried by birds or wind. Single trees of *Elaeagnus angustifolia*, *Prunus armeniaca*, *Populus alba*, *Morus alba*, *Salix alba* L. up to 15 years old grow on the watershed dams. The grass cover of the dams is sparse, it is made up of weeds: *Grindelia squarrosa* (Pursh) Dunal, *Echium vulgare*, *Lactuca tatarica*, *Equisetum arvense* L., *Plantago major* L., *P. lanceolata* L., *Atriplex tatarica* L., *Ambrosia artemisiifolia*, *Lactuca serriola*, *Erigeron canadensis* and others. *Phragmites australis* and *Humulus lupulus* grow in sumps. In this territory, 17 nesting and 8 species of birds arriving for hunting and rest have been identified. An increase in the species diversity of birds is observed during the period of spring and autumn migrations, which requires further study.

On the PMP territory there are small technogenic reservoirs overgrown with *Phragmites australis* and other plants of waterlogged biotopes. In these areas nesting of *Acrocephalus arundinaceus* and *A. scirpaceus*, *Fulica atra*, *Luscinia svecica* and others has been recorded. The wastewater treatment plants in Horishni Plavni city is located on the PMP territory next to the drainage canal. They are represented by several operating sites for filtration of communal wastewater and a site for reclamation. In total, 14 species of birds and 16 species that feed and rest here have been recorded nesting on their territory.

In 2022, the following species were recorded on the territory of the silt plots during the nesting period: *Himantopus himantopus* – 3 pairs (Fig. 8), *Vanellus vanellus* – 2 pairs, *Charadrius dubius* – 2 pairs, *Tringa totanus* – 1 pair, *Motacilla alba* and others. During the migration period, swarms of *Philomachus pugnax* and other Charadrii have been recorded at the treatment plant zones. In July–August, numerous flocks of *Sturnus vulgaris* feed here, as well as various birds of prey. Due to the closed mode of the plant, during the migration period, an increase in the diversity and number of birds is expected.

Fig. 8. *Himantopus himantopus* nesting at wastewater treatment plants

Various buildings and technical constructions of the PMP are inhabited by synanthropic species: *Streptopelia decaocto*, Corvidae (*Garrulus glandarius*, *Pica pica*, *Corvus monedula*, *C. cornix*, *C. corax*), *Parus major* and *P. caeruleus*, *Galerida cristata*, *Passer montanus* and *P. domesticus*, *Sturnus vulgaris*, and species less adapted to similar technogenic conditions: *Phoenicurus ochruros*, *Oenanthe oenanthe*, *Motacilla alba*. On the territory near the PMP and the administrative building, autochthonous and introduced species of trees and shrubs are planted. Nests of *Chloris chloris*, *Carduelis carduelis*, *Acanthis cannabina*, *Serinus serinus*, *Turdus philomelos* and others are placed in these plantings. In green spaces of *Populus alba* nesting of *Oriolus oriolus*, *Garrulus glandarius*, *Columba palumbus* has been registered. *Sylvia communis* and *Acrocephalus palustris* nest on wastelands overgrown with forbs and ruderal vegetation. *Falco tinnunculus* and *Apus apus* nest in the attics of buildings.

General ecological and faunistic review of the PMP technogenic zones avifauna. Among 140 species recorded in different technogenic territories, 103 species belong to the nesting avifauna, which is 73.6% (n = 140) of the total number of species (Fig. 9). Representatives of the order Passeriformes predominate (62.0%, n = 103), subdominant species are representatives of the orders Ciconiiformes, Falconiiformes and Charadriiformes. The least common order of Caprimulgiformes is represented by one species of *Caprimulgus europaeus*, which is found only in dumps.

The ornithocomplexes of the dumps and PMP territory demonstrate a high similarity with each other in terms of the Sorensen coefficient (Cs = 0.7). Birds show the minimum similarity in the PMP territory and the tailing dump (Cs = 0.1), as well as in the bypass canal and the tailing dump territory (Cs = 0.1, Table 3).

The avifauna of all studied technogenic territories is divided according to the habitation status into transient, nesting and nomadic. Most of the species are nesting (73.6%, n = 140), nomadic species are less common (22.9%) and transient species are very rare (3.5%, Fig. 10). Nesting species predominate on the PMP territory (90.4%, n = 52) and bioengineering facilities (68.0%, n = 25). Nomadic species dominate in the tailings territory (70.8%, n = 24) and the drainage canal (64.7%, n = 51). Transient species are rarely found on the territory of dumps (4.0%, n = 75), the PMP (1.9%, n = 52), and the bypass canal (3.6%, n = 113).

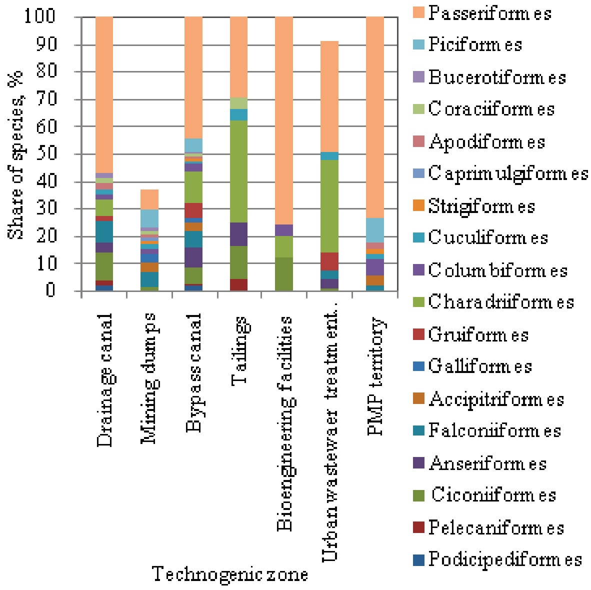

Fig. 9. Taxonomic characteristics of the avifauna of different PMP technogenic territories

Most of the bird species found in the study area have conservation status (Fig. 11). 16 species of birds are protected under the Bonn Convention (Appendix II), 10 species under the Berne Convention (Appendix I). Seven species of birds are protected on the territory of the Poltava region. Five species of birds listed in the Red Book of Ukraine are also registered: *Columba oenas*, *Himantopus himantopus*, *Hieraaetus pennatus*, *Haliaeetus allbicilla*, *Milvus migrans*.

According to the landscape-genetic principle of faunal complexes' classification, the avifauna of our research territory is divided into 11 groups. The largest part of the species belongs to the boreal group, typical for the tailing's territory (33.3%, n = 24) and urban wastewater treatment plant (30.0%). Tropical species are constantly recorded on the territory of urban wastewater treatment plant (23.3%, n = 30), drainage (21.5%, n = 51) and bypass canals (17.7%, n = 113). The group of European forest-steppe species is found on the dump's mining territory (18.6%, n = 75) and the bypass canal (13.3%), while estuary species are recorded on the bypass canal (14.2%) and the PMP territory (20.0%, n = 52). Sub-Mediterranean species are less common than others in the territory of dumps (4.0%), bypass (2.6%) and drainage (3.9%) canals and a plant (3.8%, Fig. 12).

Nesting bird species are represented by 11 faunogenetic complexes. Most of them belong to the groups of nemoral (14.6%, n = 103), forest-steppe (14.6%) and tropical (12.6%), species. Desert-mountain species are subdominant (11.7%). Less numerous categories were ancient nemoral (10.7%), alluvial (9.7%), estuary (9.7%), boreal (9.7%), desert-steppe (3.9%), sub-Mediterranean (2.9%) and ancient-forest (1.9%) birds

(Fig. 13). Nomadic species belong to 7 landscape-genetic faunistic complexes. Representatives of the tropical (28.1%, n = 32), boreal (28.1%), and estuary (25.0%) groups are dominant. The ancient-forest and ancient-nemoral (6.3% each), as well as alluvial and forest-steppe (3.1% each) groups are less represented. Transient bird species are represented by only 4 faunogenetic complexes, among which boreal species predominate (40.0%, n = 5). Forest-steppe, ancient-forest and tropical birds are much less common (20.0% each).

Table 3
Calculations of the similarity of avifauna using the Sorensen coefficient

Technogenic zone	Bypass canal	Drainage canal	Mining dumps	Bioengineering facilities	Urban wastewater treatment plant	PMP territory	Tailings
Drainage canal	0.5	–	–	–	–	–	–
Mining dumps	0.5	0.3	–	–	–	–	–
Bioengineering facilities	0.4	0.6	0.3	–	–	–	–
Urban wastewater treatment plants	0.3	0.4	0.1	0.4	–	–	–
PMP territory	0.4	0.2	0.7	0.2	0.2	–	–
Tailings	0.1	0.2	0.2	0.3	0.2	0.1	–

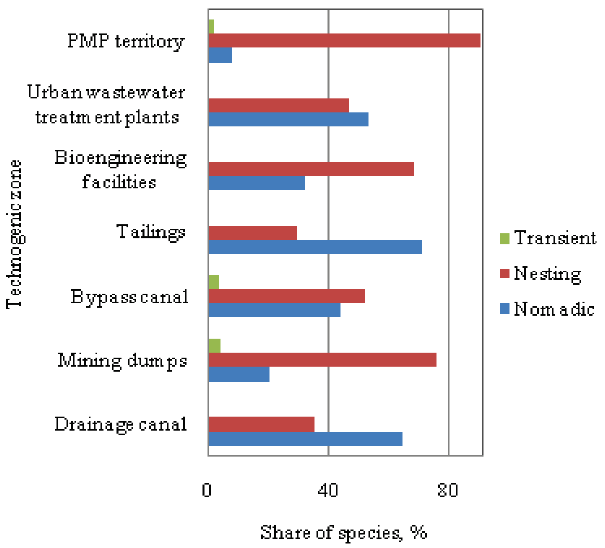

Fig. 10. Distribution of species diversity by habitation status

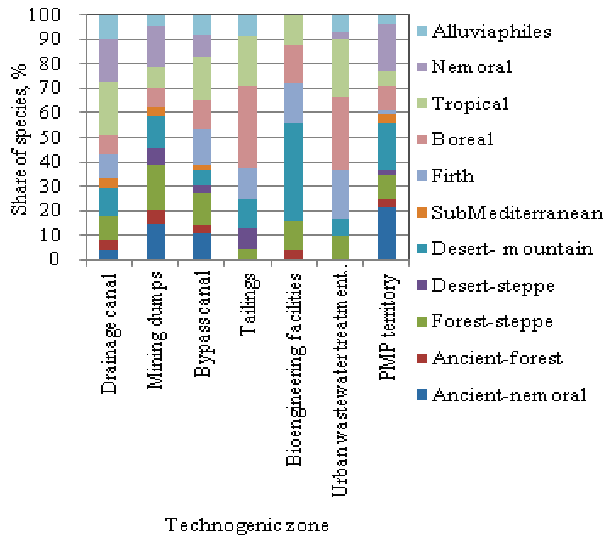

Fig. 12. Distribution of species diversity by faunogenetic complex

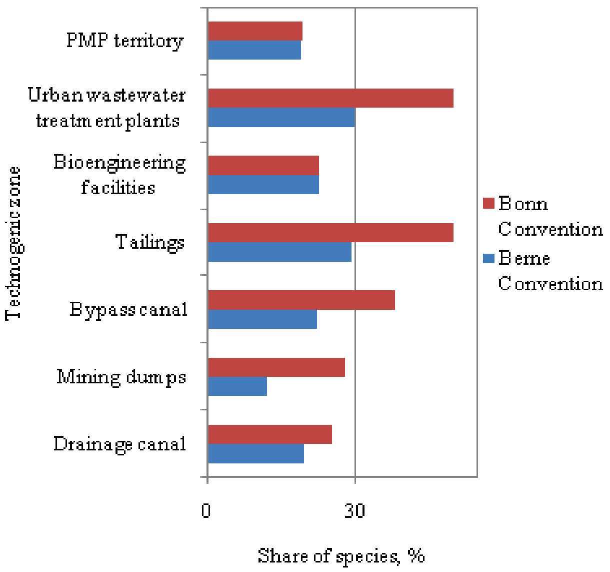

Fig. 11. Distribution of species diversity by conservation status

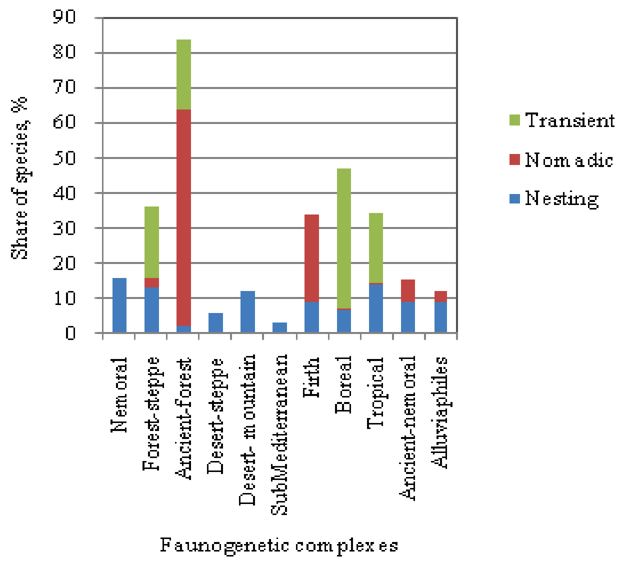

Fig. 13. Habitation status of species diversity in faunogenetic complexes

The avifauna identified in the study area is represented by four ecological groups: limnophiles, campophiles, dendrophiles and sclerophiles (Fig. 14). On the PMP territory and mining dumps, dendrophiles dominate (67.3%, n = 52 and 66.7%, n = 75, respectively). The subdominants are limnophiles registered on the territory of urban wastewater treatment plant (66.7%, n = 30) and tailings (62.5%, n = 24). Significantly fewer campophiles were found (16.7% in the territory of tailings and 12.0%, n = 25 in bioengineering facilities), as well as sclerophiles (23.1% in the PMP territory and 17.3% in mining dumps).

Discussion

Birds have been used to study the success of mining dump remediation due to their ability to quickly respond to changes in the environment (Galligan et al., 2006; Devictor et al., 2008). Birds distribute plant seeds not only within ecosystems, but also between them (Bulakhov et al., 2008, 2015). A significant part of the PMP territory is not accessible to people, so it turns into a kind of reserve for birds during migration, foraging and rest during the reproductive period. Some of the most plastic species remain here for nesting.

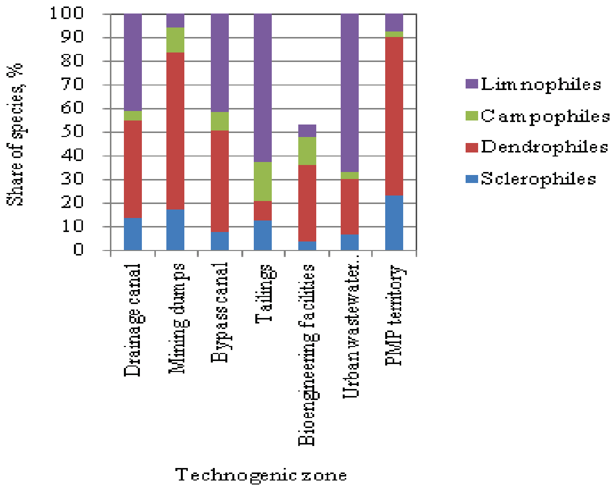

Fig. 14. Distribution of species diversity by ecological groups

The avifauna of the PMP studied by us is 45.6% of the total species (n = 307) known for Poltava region and 64.7% of the total nesting species (n = 150) of the region. This is 10.0% more than the birds found here in the summer period in 2015–2016 (Gavris et al., 2017), which may indicate an increase in diversity over the past five years. The colonization of technogenic territories by birds occurs due to their penetration from the surrounding natural and anthropogenic ecosystems. Most of the dominant bird species in the areas adjacent to the mine are common and numerous. Initially, birds visit these territories in early spring and winter (Ingold, 2022). Birds that regularly visit dumps and technogenic wetlands can be considered as a reserve for increasing the number of nesting species (Baczyńska et al., 2017).

With the development of vegetation cover on technogenic substrates and an increase in forest plantations, the faunal complex of birds in open spaces gradually changes to forest-edge and forest complexes (Ingold & Dooley, 2013; Yunanto et al., 2021). The most optimal solution is the afforestation of dumps with pine-deciduous crops (Bell et al., 2017) and the natural restoration of vegetation on the technogenic landscapes of PMP complex with the formation of a multi-species tree-shrub layer, which contributes to the biodiversity of nesting birds.

Mixed forest biotopes are trophically and topically attractive for insects and other invertebrates that form the food base of dendrophiles (Chaplygina et al., 2018; Chaplygina & Pakhomov, 2020; Yuzyk & Chaplyhina, 2021; Yarys et al., 2021). Most birds feed on widespread insect species, which allows them to quickly colonize new technogenic territories (Devictor et al., 2008). On the contrary, some experts suggest regularly removing woody vegetation in quarries, thus forming a prototype of natural steppe biotopes that are usually ploughed up, which will contribute to the conservation of birds in an open complex (Lautenbach et al., 2019; Koshelev & Pakhomov 2020; Koshelev et al., 2020b).

Wetland biotopes, including man-made biotopes, such as lakes that form on the site of ore-mining quarries in different countries of the world, are important for the feeding and resting of birds (Doupe & Lymbery, 2005). Equally important are effective drainage canals (Rosa et al., 2003; Granadeiro et al., 2004; Lourenço et al., 2005). Various man-made wetlands are important for nesting of rare bird species listed in the Red Book of Ukraine. In particular, *Himantopus himantopus* is known to use the sludge beds of wastewater treatment plants for settlement and nesting (Cuervo, 2010; Alexander et al., 2011; Mamedova & Chaplygina, 2021; Chaplygina & Litvin, 2022). At present, in conditions of a significant reduction in the areas of natural ecosystems, technogenic biotopes often play the role of important centres for maintaining the diversity of regional biota and preserving rare species (Kazem et al., 2022).

Conclusion

Thus, the results of the conducted studies indicate that on the technogenic substrates of the PMP, which were completely devoid of soil, plant and animal cover 60 years ago, various types of phytocenoses have been formed by now, colonized by the corresponding ornithocomplexes.

In the floristic composition of technogenic zones where the vegetation cover was restored from scratch, there are predominantly ornithochoric and anemochoric species of vascular plants which are common in phytocenoses surrounding the PMP territory: pine and floodplain forests, field agrocenoses, private vegetable and garden orchards. Phytocenoses on the bypass and drainage canal territory, as well as bioengineering facilities, are formed by types of aquatic, shoreline aquatic and meadow vegetation with a significant participation of weeds. There are no steppe biogeocenoses in the territories adjacent to the PMP, which can explain the small number of stepants in the composition of phytocenoses in the studied technogenic territories.

The results of avifauna research suggest that, despite the increased anthropogenic impact, some technogenic biotopes play a special role in maintaining populations of various bird species and are a place of concentration of not only widespread, but also rare species. In general, on the PMP territory, we have identified 140 species of birds nesting or staying in summer, of which a significant number are rare and endangered both on the Ukraine territory and across Europe.

This proves that the conditions in technogenic territories are quite favourable for nesting birds, so they can be recommended for inclusion in some categories of the nature reserve fund of Ukraine (for example, protected tracts, natural monuments or renaturalization zones of regional landscape parks), and also considered as buffer recovery zones or territories as part of a local or regional ecological network.

The materials of this publication are part of the original research results obtained by a group of specialized scientists from seven universities of the Ministry of Education and Science of Ukraine and two research institutions of the National Academy of Sciences of Ukraine during the implementation of the research program on the study of biodiversity in the region where the enterprises of the Ferrexpo group are located (2020–2022) at the expense of the customer.

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