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Biogeochemical assessment of Donbass landscapes transformed by military actions

Biogeohemijska procena predela Donbasa transformisanih vojnim akcijama

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Abstract: The atomic absorption method spectrophotometry was used to establish the accumulation of the elements: Mn, P, Zn, Cu, Mo, Ni, Pb, Cr, La, Co, Se, As, Cd by the ruderal species *Taraxacum officinale* F.H.Wigg, which was used in phytoindication of pollution levels landscapes Donbass, transformed by military actions. A comparative assessment is provided of territories that have undergone large-scale transformations as a result of military operations, with the relatively clean territories of Donbass. In landscapes transformed by military actions, biogeochemical provinces of anthropogenic genesis have been identified: zinc-cobalt-lead (Zn-Co-Pb), copper-nickel-lead (Cu-Ni-Pb), phosphorus-lanthanum (P-La), nickel-cobalt (Ni-Co), in which the content of elements is orders of magnitude higher than background levels. Morphological and anatomical pathologies of the indicator species *Taraxacum officinale* were established within each province. In the biogeochemical provinces of Donbass, a high accumulation of the main pollutant elements by the indicator plant *Taraxacum officinale* was observed, which indicates the high adaptive and phytoremediation potential of this species, as well as the current unsuitability of these lands for agricultural needs and the need for their restoration.

Keywords: biogeochemical monitoring, heavy metals, indicator plants, trace elements, environmental pollution.

Sažetak: Metoda atomske apsorpcione spektrofotometrije korišćena je za utvrđivanje akumulacije elemenata: Mn, P, Zn, Cu, Mo, Ni, Pb, Cr, La, Co, Se, As, Cd od strane ruderalne vrste *Taraxacum officinale* F.H.Wigg, koja je korišćena u fitoindikaciji nivoa zagađenja predela Donbasa, transformisanih vojnim dejstvima. Data je uporedna procena teritorija koje su pretrpele velike transformacije kao rezultat vojnih operacija, sa relativno čistim teritorijama Donbasa. U predelima transformisanim vojnim dejstvima, identifikovane su biogeohemijske provincije antropogene geneze: cink-kobalt-olovo (Zn-Co-Pb), bakar-nikl-olovo (Cu-Ni-Pb), fosfor-lantan (P-La), nikl-kobalt (Ni-Co), u kojima je sadržaj elemenata redova veličine većih od fonskih nivoa. Morfološke i anatomske patologije indikatorske vrste *Taraxacum officinale* utvrđene su u svakoj provinciji. U biogeohemijskim provincijama Donbasa primećena je visoka akumulacija glavnih elemenata zagađivača indikatorskom biljkom *Taraxacum officinale*, što ukazuje na visok adaptivni i fitoremedijacijski potencijal ove vrste, kao i na trenutnu nepogodnost ovih zemljišta za poljoprivrednu upotrebu i potrebu za njihovom sanacijom.

Ključne reči: biogeohemijski monitoring, teški metali, biljke indikatori, elementi u tragovima, zagađenje životne sredine.

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INTRODUCTION

Due to the ongoing military actions in Donbass from 2014 to the present, heterogeneous landscapes in geomorphological and biogeochemical terms have formed, so many agricultural and recreational lands are not used. These areas require comprehensive research, which will serve as the basis for developing methods for their recovery. Among modern methods of studying the state of the environment, the biological method plays a significant role. A significant role in the biological method is given to indicator plants of the elements content, which make it possible to determine the level of elements content in various natural environments, many of which are accumulators of one or more elements. These plants include: *Lemna minor* L. (Baranovskaya et al., 2024; Kekina et al., 2020), *Cladochaeta candidissima* (Bieb.) DC. (Golubev, 2021, 2021a, 2025; Golubev & Degtyarev, 2025; Golubev & Ermakov, 2021; Golubev et al., 2021; Golubev et al., 2025), *Myricaria bracteata* Royle (Golubkina et al., 2025), *Taraxacum officinale* F.H. Wigg (Safonov, 2024, 2024a, 2025, 2025a; Safonov et al., 2024), species of the genus: Allium L. (Golubev & Golubkina, 2019; Golubev et al., 2003), Astragalus L. (Golubkina & Papazyan, 2006), Tamarix L. (Golubkina et al., 2025), Betula L. (Golubev et al., 2021), etc. As a rule, native (Golubev, 2021, 2021a; Golubev & Ermakov, 2021; Golubev et al., 2021; Golubev et al., 2025) and/or ruderal species are used as indicator plants of environmental pollution (Safonov, 2024; Safonov et al., 2024).

The indicator plant of anthropogenic pollution the perennial herbaceous plant - *Taraxacum officinale* F.H. Wigg (Asteraceae), we used in our work. Dandelion is widespread in the Donbass region and is a weed plant (Safonov et al., 2024). A comprehensive biogeochemical assessment of the Donbass landscapes transformed as a result of military action was carried out. The degree of pollution of the studied area was judged by the elemental composition of the vegetative organs of dandelion and indicator morphological and anatomical features. In addition, a calculation was made to determine the life strategy of dandelion in the landscapes transformed by military actions (visualization of life strategies in triangle of the Grime-Ramensky).

1. MATERIALS AND METHODS

Field investigations was conducted on the territory of the Donetsk People's Republic (DPR). A monitoring network of sample plots, evenly spaced, was established in the Central Donbas region. Each sample plot was 200 square meters in size. Data from 203 sample plots was included in the assessment of the status of all ecotopes in the Donbas region (Safonov, 2024). The present research focused on 21 survey areas, which represent ecotopes of the previously existing agricultural sector and recreational areas disturbed as a result of military events. The entire surveyed territory of landscapes transformed by military actions occupies an area of 2488.32 km^2 within the monitoring network, which is 48% of the total observation area within the Central Donbass. Approximately 34% of the entire surveyed area of Central Donbas falls within the zone of acute military conflict and was studied at 10 survey sites located in the northwestern part of the DPR. The remaining territories (14%) were studied at 11 survey sites, five of which were located directly outside the zone of acute military conflict, while six were relatively undisturbed areas.

The object of the study was the herbaceous perennial plants *Taraxacum officinale* F.H. Wigg (Asteraceae), widely distributed throughout the republic (Safonov, 2025a). It is known that dandelion is often used as an object of environmental monitoring (Safonov, 2024; Safonov et al., 2024; Zinicovscaia et al., 2024). Plants were sampled diagonally. Vegetative plants were sampled in five replicates along the diagonal of each plot at 7-10 equally spaced points to obtain a composite sample and then an average sample. The collected plant samples (leaves) were subjected to air-shadow drying. The plants were spread in a thin layer on metal grates and dried at room temperature. Leaves were collected from each dried research object and then carefully mixed to form an average sample. The prepared samples were placed in polyethylene bags, labeled, sealed tightly, and transported to the laboratory for further analysis.

In the laboratory, plant samples were ground up. To obtain a representative sample, the samples were homogenized by double quartering, placed in porcelain crucibles and dried in a drying oven at a temperature of 60-65ºC until constant weight. The content of 13 elements was studied: Mn, P, Zn, Cu, Mo, Ni, Pb, Cr, La, Co, Se, As, Cd. According to standard methods the content of elements in the leaves was determined after acid digestion of samples by atomic absorption spectrophotometry (AAS) on certified Saturn-3 and Solar-M devices (Thermo Electron, USA) in flame and electrothermal analysis options with deuterium and Zeeman background correctors (Food raw materials and products, 2002; Khavezov & Tsalev, 1983; Pupyshev, 2009). The accuracy of the sample analysis was controlled by comparison with certified samples. Statistical analysis of the research results was performed using the Statistica 12 program.

It is known, that morphological and anatomical changes in indicator plants play a significant role in

the phytoindication of biogeochemical anomalies of landscapes transformed by military actions (Safonov, 2024a). Visual assessment of *Taraxacum officinale* was carried out in field conditions based on morphological characteristics. Morphological characteristics of the leaf blade were taken into account: shape, degree of dissection, and symmetry. The uniformity of pigments distribution in the leaf blade was visually assessed. Based on the above characteristics, a conclusion was drawn about the presence or absence of stress factors. Anatomical studies of *Taraxacum officinale* leaves were conducted using an MBI-11 microscope in laboratory conditions.

2. RESULTS AND DISCUSSION

For the research, territories with the maximum transformation of ecotopes that occurred as a result of military actions were selected. For a comparative geochemical assessment of the above-mentioned clusters, we studied areas with minimal transformation of ecotopes located to the northeast of Khartsyzsk. The biogeochemical series of these areas is presented as a sequence of elements: Mn (2100) > P (1600) > Zn (1530) > Cu (194) > Mo (41.4) > Ni (36.1) > Pb (32.7) > Cr (26.9) > La (10.1) > Co (4.5) > Se (4.2) > As (2.8) > Cd (0.87).

As a result of the researches, a positive correlation was established between the characteristics of teratogenesis at different levels of organization and localization of morphological pathologies: the architectonics of shoot formation, the symmetry of habitus, paired organs (leaf blade or flower with a ligulate bend of the corolla, etc.), dystopia and elimination of generative organs, multiple proliferations, pubescence of plant vegetative parts, the pollens structures and individual conformational tissues in the embryonic apparatus of dandelion (Safonov, 2025, 2025a).

It was established, that the inflorescences had different morphotypic manifestations in accordance with the ranked ranges of values of the military disturbance factor in ecosystems. Dandelion basal rosettes varied morphologically, resulting in qualitative signaling differences at the macro- and micro-levels of plant structure. Four phenotypic lineages were identified, manifesting depending on the geochemical contrasts in landscapes, transformed by military actions.

Based on the elemental composition and macropathologies of *Taraxacum officinale*, 4 biogeochemical provinces (anomalous zones) were identified, and a ranked series of elements of phytogeochemical background values by elemental composition was presented (Table 1).

Table 1. Biogeochemical anomalies (provinces) of DPR landscapes according to AAS analysis of plant samples

Biogeochemical anomalies (biogeochemical provinces)	**Location**	**Ranked elements series, mg/kg**
Zinc-cobalt-lead (Zn-Co-Pb)	Northwest of Donetsk. The vicinity of the Spartak microdistrict.	**Zn** (**2837**) > Mn (1900) > P (1550) > Cu (207) > **Co** (**190**) > **Pb** (**112**) > Mo (42,6) > Ni (35) > Cr (26,1) > La (11,4) > Se (4,6) > As (2,8) > Cd (0,88)
Copper-nickel-lead (Cu-Ni-Pb)	Southwest of Gorlovka. The environs of the Mikhaylovka village.	**Cu** (**1830**) > Mn (2070) > P (1500) > Zn (1540) > **Ni** (**290**) > **Pb** (**160**) > Mo (40,9) > Cr (27) > La (9,9) > Co (4,8) > As (2,9) > Se (4,5) > Cd (0,81)
Phosphorus-lanthanum (P-La)	North of Donetsk. The territories of Avdeevka and Yasinovataya	**P** (**5950**) > Mn (2210) > Zn (1380) > Cu (193) > **La** (**179**) > Mo (38,8) > Ni (34,7) > Pb (30,9) > Cr (25,5) > Co (4,3) > Se (2,7) > As (2,6) > Cd (0,73)
Nickel-cobalt (Ni-Co)	Northwest of Yenakiyevo. Yenakiyevo urban district	Mn (2250) > P (1670) > Zn (1590) > **Ni** (**628**) > Cu (201) > **Co** (**72,3**) > Mo (44) > Pb (30,5) > Cr (25) > La (10,5) > Se (3,9) > As (2,4) > Cd (0,52)

The biogeochemical province zinc-cobalt-lead (Zn-Co-Pb), identified by significant concentrations of Zn (2837.2 ± 59.51 mg/kg), Co (190.4 ± 5.33 mg/kg) and Pb (112.2 ± 4.47 mg/kg) in plants, is located in the agglomeration Yasinovataya, northwest of Donetsk, in the vicinity of the Spartak microdistrict (Table 1). Compared with relatively background areas, the values for the content of Zn, Co and Pb in landscapes transformed by military actions exceed the concentrations of Zn, Co and Pb by 1.8, 42.2, & 3.4 times, respectively. Under the conditions of the zinc-cobalt-lead province, plants

showed signs of xerophytization: the surface of the leaf apparatus decreased, the upper lobe of the leaf was reduced, the pigment composition changed, chlorophyll was destroyed, and anthocyanins appeared.

The copper-nickel-lead biogeochemical province (Cu-Ni-Pb), identified by significant concentrations of Cu (1830.5 ± 48.61 mg/kg), Ni (290.2 ± 10.79 mg/kg) & Pb (160.3 ± 6.91 mg/kg) in plants, was recorded in areas located to the southwest of Gorlovka, in the vicinity of the Mikhailovka village (Table 1). The content of Cu, Ni and Pb elements in landscapes transformed by military actions significantly exceeds these indicators in comparison with the urban district of Khartsyzsk (Table 1) by 9.4; 8 & 5 times, respectively. In the conditions of the copper-nickel-lead province (Cu-Ni-Pb), morphopathologies were observed in Taraxacum officinale: the leaves without dissection, elongated along the main vein, the anastomotic network of venation and pubescence is compacted.

The phosphorus-lanthanum biogeochemical province (P-La), identified by significant concentrations of P (5950 ± 32.2 mg/kg) and La (179 ± 5.8 mg/kg) in indicator plants, was registered in areas adjacent to the urbanized landscapes of Avdeevka and Yasinovataya (Table 1). Compared with regional background values, these indicators in the war actions zone exceed the concentrations of P and La by 3.7 & 17.7 times, respectively. Element's concentrations (P and La) in plants exceed the values for ecologically safe regions (Raven et al., 2018; Zhang et al., 2021) by 22-45 times for phosphorus content and by 39-57 times for lanthanum content (Kastori et al., 2023; Martina et al., 2025; Sharma et al., 2024; Vorob'ev et al., 2024; Jovanović, 2025).

While P and La are not strictly regulated in agriculture and in plant-based foods (Jovanović & Mentus, 2025; Kastori et al., 2023; Raven et al., 2018; Vorob'ev et al., 2024; Zhang et al., 2021), such high levels of these elements are alarming and signal trouble and significant transformation of biotopes violated by military action. It was established that in the phosphorus-lanthanum biogeochemical province (P-La), plants exhibited hypertrophy of the leaf's rosette, the degree of its dissection decreased, and the distal parts of the leaf blades increased . Pigment composition also changed. Chlorophyll was destroyed, and anthocyanins appeared in the peripheral areas of the upper leaf blade. These morphological and physiological changes in *Taraxacum officinale* indicated the presence of stress factors.

The nickel-cobalt biogeochemical province (Ni-Co), identified by very high concentrations of Ni (628.4 ± 24.11 mg/kg) and Co (72.3 ± 2.87 mg/kg) in plants, is registered in areas located to the northwest of the Yenakiyevo city (Yenakiyevo urban district; Table 1). Compared to the region's background values, the nickel and cobalt content in the combat zone exceeded these figures by 17.4 and 16 times, respectively. The nickel-cobalt biogeochemical province is characterized by morphological and anatomical changes in the dandelion leaf blade. In the leaf epidermis, changes in the stomatal apparatus were observed: the stomatal apparatus of the anomocytic type became asymmetrical, in 40-55% of cases, stomatal apparatus of the diacytic and paracytic types were observed, which was assessed as a pathological manifestation in organogenesis. Morphological changes in the leaf have been identified: the leaf lacked lobes, lobes, and segments, the leaf margin was wavy. The increased leaf assimilation surface indicates a process that is the reverse of xerophytization-hypertrophy and mesophytization of the dandelion vegetative organs.

At the macromorphological level, the strategy of occupation dandelion of territory after a sharp disturbance of the soil cover as a result of explosions plays a significant role. This strategy of capturing the temporarily vacated soil surface by the first plants can be implemented in different ways in different plant species. In *Taraxacum officinale*, maximum explerence was observed - capture of the substrate surface, increased reproduction and dispersal.

CONCLUSION

In the context of profound transformations of the landscape systems of Central Donbass as a result of military actions, areas of significant biogeochemical contrast with the dominance of individual elements and their groups in comparison with relatively background areas were noted. Using the phytoindication method (based on the elemental composition of plants and plant morphopathologies) in landscapes transformed as a result of military actions, biogeochemical provinces were identified: phosphorus-lanthanum (P-La), zinc-cobalt-lead (Zn-Co-Pb), copper-nickel-lead (Cu-Ni-Pb), nickel-cobalt (Ni-Co), in which the content of elements was orders of magnitude higher than regional background indicators. It was established that the phosphorus-lanthanum biogeochemical province arose as a result of military actions. With radical disruption of geochemical cycles, morphological and anatomical changes, as well as pathologies, were established in the indicator species *Taraxacum officinale* within each biogeochemical province.

The calculation carried out in determining the life strategy of *Taraxacum officinale* showed that this

species had a strategy of capturing the vacated area of soil cover and maximum explerence. The results of the studies showed, that dandelion plant have a high tolerance to pollutant elements in the studied landscapes transformed by military actions and can be used for soil phytoremediation.

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