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Adaptive Responses of Herbaceous Plants and Hortobiont Arthropods during the Formation of Biocenoses on Rock Dumps of Opencast Coal Mines of Kemerovo Region

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ABSTRACT

It was established experimentally that the environmental conditions of the rock dump cause morphological and anatomical changes in leaves of the common dandelion: the leaf area is reduced and its thickness is increased mainly due to the increase in the mesophyll; the number of stomata of the upper and lower epidermis and the stomatal index of the upper epidermis are reduced.

Distinctive communities of hortobiont arthropods are formed on the rock dumps with the predominance of insects of Class Ectognatha and a significant increase in their population density in comparison with the control condition. The dominant group of hortobionts includes 9 orders (Homoptera, Heteroptera, Coleoptera, Hymenoptera, Diptera, Orthoptera, Thysanoptera, Neuroptera, Lepidoptera). The main increase in the number of hortobionts on the rock dump was observed in Diptera and Heteroptera. The herbage on the rock dump is mainly populated by phytophagous insects – leaf-eating and leaf-sucking phytophages. Predators include Coleoptera (Coccinellidae, the ground beetles, Staphylini), predatory bugs and ants.

It was established that anatomical and morphological characteristics of leaves of the common dandelion significantly correlate with the complex air quality index (AQI) and dust deposition. The population density of hortobiont insects, Hemiptera, and Hymenoptera insects significantly correlates with a wider range of atmospheric pollutants – AQI, deposition of dust, nitrates and sulfates. The results obtained can be viewed as a distinctive response of the biocenosis components to the environmental conditions of the rock dump.

KEYWORDS

Opencast Coal Mine, Rock Dumps, Environmental Conditions, Common Dandelion, Hortobiont Arthropods, Morphology.

Introduction

Human activity is one of the most important causes of biodiversity loss (Peñas, Benito, Lorite et al. 2011). The Kuznetsk Basin is one of the largest coal basins in the world where numerous opencast coal mines and dumps can be observed on the wastelands of coal-mining enterprises. Despite large-scale recultivation of the disturbed lands, the area of dumps is expected to grow by 20 % by 2020, and the total area of the disturbed lands requiring rehabilitation will increase by about half (Litvinenko 2008; Materials for the state report... 2010). In such conditions, it is important to study the formation on the dumps of coal mining enterprises of pioneer communities of plants and small invertebrates that inhabit the grass layer in various types of biotopes and their adaptive responses that contribute to the formation and functioning of stable cenoses.

A high degree of stability of some species of higher plants is ensured by a combination of morphological, physiological and anatomical adaptive responses, which makes these plants potentially able to improve the quality of the natural environment – urban and industrial areas and technogenically disturbed lands (Neverova and Bykov 2015; Legoshchina et al. 2016; Neverova and Bykov 2016). Plants adaptations are primarily associated with reorganization of their assimilating organs, which, due to their gas exchange function, are highly sensitive to external impact (Neverova et al. 2013; Legoshina et.al. 2013; 2017). It is known that morphological and anatomical reorganization change the physiological status of plants in extreme living conditions for more efficient use of environmental resources (Menshakova et al. 2008). Among the inhabitants of the herb layer in cenoses of various degrees of disturbance, including anthropogenic ones, the most distinctive group is that of hortobiont arthropods. Hortobionts

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are found in all landscape zones, in ecosystems of varying degrees of disturbance; they are characterized by a rapid response to changes in environmental factors and are therefore suitable for studying the state of ecosystems. In most terrestrial ecosystems, hortobionts are mainly represented by Arachnida and Insecta. Most often it is insects of the orders Homoptera, Hemiptera, Hymenoptera and Diptera. Of these, clear responses to changes in habitat conditions were shown by Hemiptera (Zolotarev 2005).

The goal of this research was to study the adaptive responses of herbaceous plants as exemplified by *Taraxacum officinale* Wigg. and hortobiont arthropods in the formation of biocenoses on rock dumps of the Kedrovsky opencast coal mine in the Kemerovo region.

Materials and Methods

The research was carried out on the Yuzhny dump of the Kedrovsky coal mine. The dump has a plain and sloping ground 58 m high, with the area of 599.3 ha. The dump rocks are represented by sandstone (60 %), siltstones (20%), argillites (15%), loams and clays (5%) (Fig. 1).

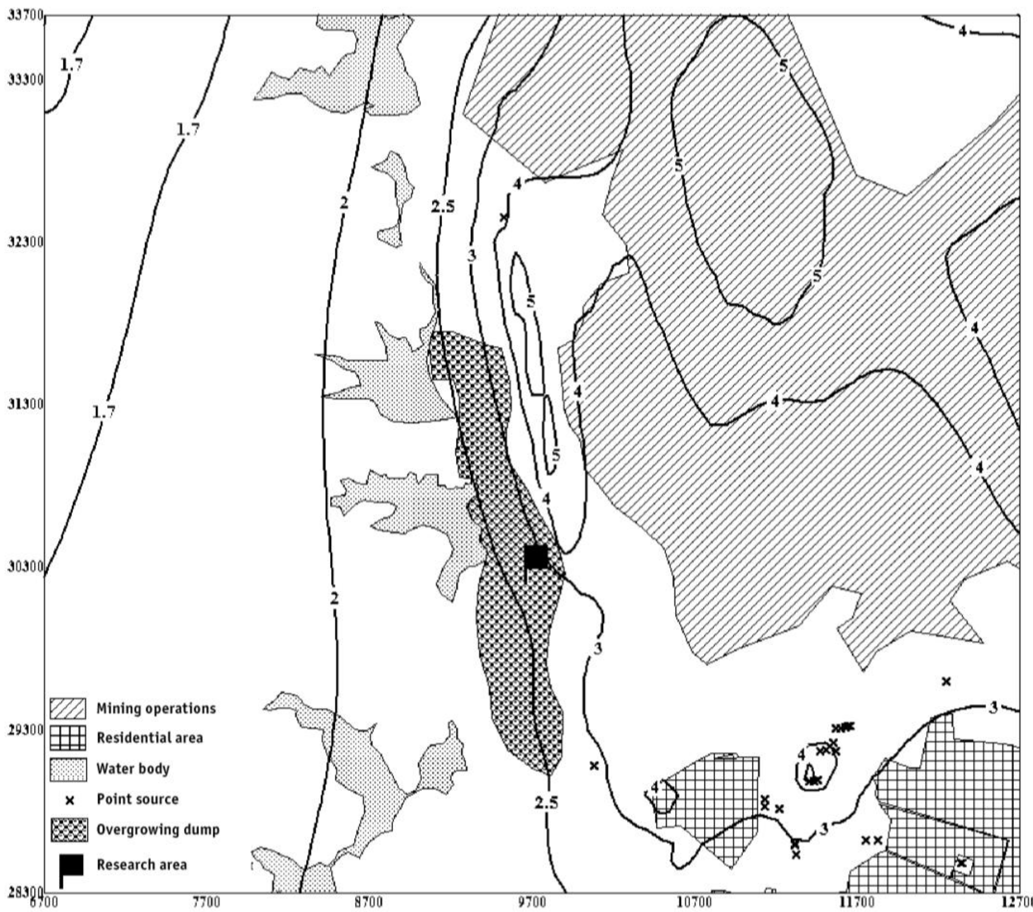

Figure 1. Surroundings of the Research Area with Isolines

The experimental plot is located at the top of the graded dump. A biocenosis lives for 7–10 years. Technical and biological stages of land reclamation have been carried out on the dump (*Pinus sylvestris* L. and *Onobrychis arenaria* (Kit.) have been planted); it is showing the initial stages of formation of meadow communities; there are separate areas of stony placers with an area of up to 3 m^2 made up of different formats of dump rock, completely devoid of vegetation. The projective cover is up to 50%, in rocky areas – below 10%. Turfness is not observed. The grass layer is dominated by *Onobrychis arenaria*, *Taraxacum officinale* Wigg, *Melilotus officinalis* (L.) Pall., *Artemisia sericea* Web. Ex Stechm., *Picris hieracioides* L. Embryonic soils are characterized by an alkaline reaction

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(pH of the water extract being 7.1–7.7), average humus content (3.5%), low content of mobile forms of phosphorus (10–50 mg/kg) and nitrogen (3.6–6.0 mg/kg), high content of potassium (100–140 mg/kg), lack of productive moisture (19–22 mm in 0...20 cm layer). The control plot was located 15 km northwestward of the dumps on the border of the birch forest. A large area (about 80%) of the plot is occupied by a grass meadow. The projective cover is 95–100%, the soil is not turfed. The grassland communities are dominated by *Centaurea scabiosa* L., *Hieracium umbellatum* L., *Lathyrus pratensis* L., *Achillea asiatica* Serg., *Taraxacum officinale* Wigg.).

The soils of the plot are represented by chernozem meadow medium heavy loam with a high humus content (9.65%), a relatively high content of phosphorus (83.0 mg/kg) and potassium (171.0 mg/kg), a weak acidic reaction of the soil solution (pH 6.1...6.3) and an ample amount of productive moisture (50-60 mm in 0...20 cm layer).

To estimate the impact of industrial air emissions on vegetation in the research area, ERA-VOZDUH software package was used [https://lpp.ru], which implements the regulatory models for calculating maximum single allowable concentration and average annual concentration adopted in Russia since 01.01.2018, as specified in the Order (Order of the Ministry of natural resources of Russia... 2017). The models allow us to calculate one-time and average annual atmospheric pollution from both gaseous and sedimentary emissions of impurities from industrial sources based on data on emissions by air pollution sources and meteorological parameters typical for a given area.
It is obvious that the state of plants depends primarily on the long-term impact of pollutants, which is determined by the average annual concentrations in the surface layer of the atmosphere and the annual aerosol deposition on the soil cover. The module for calculating particle deposition on the underlying surface (Bykov et al. 2002), which is a research supplement to the ERA-VOZDUH software, was used in the conditions of Kuzbass many times and showed a good agreement between the calculation results and field observations (Bykov et al. 2006).

The initial data for calculating the long-term average concentration, in addition to the source parameters, includes three distribution densities: wind direction $p_1(\varphi)$; wind speed $p_2(u)$; dimensionless parameter λ of the intensity of turbulent mixing $p_3(\lambda)$. For normative calculations, these distributions, which determine the pattern of long-term atmospheric pollution for the research area, are requested from the Voeikov Main Geophysical Observatory (Saint-Petersburg). The function $p_1(\varphi)$ (smoothed wind rose) for a specific averaging time can be obtained from an 8-point wind rose plotted using standard meteorological observations. However, to assess the impact of pollutants on plants over a long period of time, it is preferable to use the climate (average for at least 5 years) wind rose which can be found in a special meteorological file sent from the Main Geophysical Observatory.

The research area is influenced by air pollution sources not only from the Kedrovsky coal mine, but also from the city of Kemerovo, powerful sources of energy and chemical enterprises that are located 20 km southwestward of the experimental plot, i.e. from the direction of prevailing winds. The parameters of air pollution sources of urban enterprises and roads were taken from the inventory of the consolidated volume of the Kemerovo maximum permissible emissions (MPE) (KOJSC Azot, Kemerovo TPP, Kemerovo GRES, JSC Koks, Novokemerovskaya TPP, highways, Oblomunenergo), and the source parameters of the Kedrovsky mine are based on the corporate volume of the MPE developed a little later.

In the process of modeling of atmospheric pollution, a conditional dimensionless composite index (CI) of the total average annual atmospheric pollution CI= $C_1/ MAC_{c1} + C_2/ MAC_{c2} + ... + C_n MAC_{cn}$, where C_i, i=1,2,..., n – the total average annual ground level concentration of impurities for all sources, MAC_{ci} – the corresponding average daily hygienic maximum allowable concentrations, and the indices 1,2,..., n refer to pollutants whose average annual concentrations C_i exceed the level of 0.1 MAC_{ci}. When calculating the CI, the following substances and their compounds were taken into account: manganese and its compounds, lead and its inorganic compounds, nitrogen dioxide, nitrogen oxide, sulfuric acid, soot, sulfur dioxide, hydrogen sulfide, carbon oxide, fluoride gas compounds, chlorine, ammonium carbonate, benzene, dimethylbenzene, methylbenzene, Benz(a)pyrene, naphthalene, butane-1-ol, cyclohexanol, butyl acetate, formaldehyde, cyclohexanol, dimethylaniline, nitrobenzene, kerosene, mineral oil, saturated hydrocarbons C_{12}–C_{19}, inorganic dust containing silicon dioxide, abrasive dust, coal dust. This index is not a standard hygienic criterion, since not all the substances taken into account have a one-way effect on a person. It represents the "total technogenic load" created by industry through atmospheric transport of pollution to a particular area of the city. Table 1 shows the atmospheric emissions at the observation plot.

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Table 1. Indices of the Long-Term Impact of Atmospheric Emissions on the Research Area

Emissions studied	**Total**	**Mine contribution**	**City contribution**
Composite index (CI), number / %	2.78 / 100	1.38 / 49.8	1.40 / 50.2
Dust deposition, g/m^2 per year / %	6.79 / 100	5.68 / 84	1.11 / 16
Nitrate deposition, g/m^2 per year / %	0.31 / 100	0.11 / 36	0.20 / 64
Sulfate deposition, g/m^2 per year / %	0.16 / 100	0.03 / 16	0.13 / 84

When calculating soil contamination by atmospheric deposition, the size distribution of emissions and deposition velocities of various size fractions of particles were additionally assigned, as was done in (Bykov et al. 2006). The term "dust" in Table 1 refers to the sum of all solid particles released into the atmosphere of the city of Kemerovo and the Kedrovsky mine.

The analysis of calculated indices of atmospheric emissions in the research area shows that the most significant contribution of the Kedrovsky mine is that to the dust deposition, which is 5.68 g/m^2 per year or 84% of the total dust deposition in the research area which includes urban industrial facilities. The contribution of the mine to the composite index of atmospheric pollution in the research area is 49.8% (the contribution of the city is 50.2%). Less significant is the contribution of the Kedrovsky mine to the total amount of nitrate and sulfate deposition in the research area, which is 36 and 16%, respectively, whereas the contribution of the city is 64 and 84%, respectively.

The object of botanical research was the common dandelion (*Taraxacum officinale* Wigg.) as the most common type of perennial herbaceous plants growing on the dumps. Material preparation was carried out in dry sunny weather, according to the generally accepted rules, during the time when the green matter reaches its peak level (end of may 2016). Materials without visible signs of damage were collected from 15 sample plots of 1 m^2 from the experimental and control plots. For morphological analysis, the sample of plants from each sample plot was 10 plants, the total number from the experimental and control plots being 150 plants each. The leaf area (S) was determined by scanning and subsequent processing of the image using the *Image Tools* computer program. For anatomical analysis, the plant material was fixed in a 60 % solution of ethyl alcohol. Cross-sections were made from the middle section of the leaf blade using a microtome and placed in glycerine. Measurements of anatomical parameters of leaves (thickness of the leaf and its tissues, the number of cells in 1 mm^2 of the lower and upper epidermis, the size of stomata) were carried out using a microscope Axioscope-2+, model ZEISSN HBO103 and N XBO75 (Germany) with an ocular micrometer, camera and software. The stomatal index was calculated using the formula: $S_i = N_{st} \times 100\ \% / (N_{st} + N_{ec})$, where N_{st} – the number of stomata per 1 mm^2, N_{ec} – the number of main epidermal cells of the leaf per 1 mm*2*.

The object of zoological analysis was hortobiont arthropods – inhabitants of the herb layer. Their structure and population density were studied at the experimental and control plots. Collection and inventory of hortobionts were conducted from June to August with an interval of 7–10 days. To collect the material, the most effective method of collecting hortobionts in field studies was used –sweeping the vegetation with an entomological net (Bubnova 1988). The sweeping was carried out evenly over the entire research area, at the same time. The number of collected hortobionts per m^2 was calculated using a standard formula: $D = N / 2RLn$, where D is the density of arthropods, N is the number of specimen in the sweep, R is the radius of the net, L – path length of the net, n is the number of sweeps.

Statistical analysis of the experimental data was performed using Statistica 6.0 software package. Data interpretation was carried out using correlation analysis.

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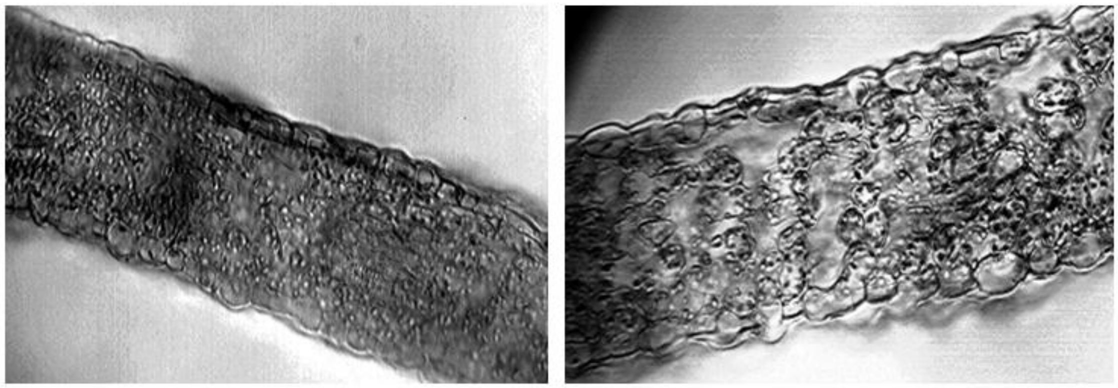
Results and Discussion

A comparative analysis of the morphology of the dandelion growing in various environmental conditions showed that the average leaf area of the plants decreases on rock dumps (by 24%), the number of leaves in the rosette tend to reduce and the leaf blade thickens (by 15%) (Fig. 2, Table 2).



A Б

Figure 2. A Cross-Section of the Leaf of *Taraxacum officinale* Wigg. (A – Control, B – Experimental Plot)

Table 2. Anatomical and Morphological Characteristics of the Leaf Blade of *Taraxacum officinale* Wigg.

Characteristics	**Control plot**	**Experimental plot**
Leaf area, cm^2	48.02±4.82	36.43±3.46*
Number of leaves per 1 plant	5.80±0.45	4.92±0.42
Leaf thickness, µm	118.10±3.22	136.25±6.22*
Thickness of tissues, µm		
- upper epidermis		
- lower epidermis	19.61±1.24	18.66±1.19
- mesophyll	16.81±0.65	15.37±0.42
	84.00±2.12	103.11±3.24*
Number of mesophyll rows	4–6	4–6

Note: marked with a * are significant differences from the control at $p<0.05$

The analysis of the anatomical structure of leaves showed that in the conditions of rock dump, the dandelion shows significantly increased thickness of the mesophyll (by 55%) and the thickness of its upper and lower epidermis tissues tend to decrease (Table 2).

The effects of human-transformed landscapes on plant communities are widely discussed in the literature. Italian researchers Gilardelli, Sgorbati, Armiraglio et al. (2015) found that different types of geomorphological surfaces of opencast mines (artificial rocks, embankments, platforms), taking into account the slope, height, rockiness and stoniness affect the species composition of plant communities and some of their morphological characteristics such as their life form, plant height and seed dissemination. These studies are important for solving the problem of mine restoration depending on the type of geomorphological surface.

Studies by Koper, Molloy, Leston et al. (2014) have shown that the negative effects of well construction, and as a result, an increase in the number of cattle around them, affect the changes in the structure and morphology of the vegetation, which should be taken into account when developing strategies to improve these effects.

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Morphological changes of the leaf are a functional response to environmental factors (Zhongqiang and Dan 2009; Scheepens et al. 2010).

As was noted earlier, rock dumps are characterized by a lack of productive moisture. It is known that when growing in arid conditions and high insolation, the thickness of the leaf blade and assimilation tissue of herbaceous plant increases (Ivanova 2014). P. É. Lauri et al. (2014) found that the lack of moisture leads to a decrease in the absolute area and mass of the leaf blade, which can be considered as an adaptive response to adverse environmental factors. It is known that adaptive responses of plants to environmental factors are non-specific. Thus, according to Akatyeva (2014) in close proximity to industrial enterprises in Isetsky district of the Tyumen region, the dandelion showed a decrease in the number of leaves per plant, height of plants, length and width of the leaf. A. 1998. Frolov (1998) points out an increase in the thickness of the leaf and mesophyll in the the common dandelion growin in urban conditions, a decrease in the size (length and width) of the cells of the spongy tissue. Lawn plants growing in the conditions of anthropogenic pollution of Yoshkar-Ola demonstrate anatomical and morphological trend towards xeromorphism: thickening of the leaf blade due to an increase in the height of the epidermis and mesophyll, reduction of intercellular spaces, and reduction of the length and width of the leaf blade (Polovnikova 2007). Under the influence of adverse environmental factors, the most obvious responses of plants are manifested in the structure of the leaf epidermis. The experimental data obtained show differences in the anatomical characteristics of the leaf epidermis of the common dandelion growing in the conditions of a rock dump (Table 3). In particular, the common dandelion growing on dumps shows a trend towards reduction of the number of cells in 1 mm2 and increase of the size of stomata in the tissues of the lower and upper epidermis, the number of stomata is significantly reduced by 1 mm2 (by 12 and 26%, respectively); the upper epidermis shows a significant decrease in the stomatal index (by 14%). Given the low amount of productive moisture in embryonic soils on rock dumps, a decrease in the stomatal index is a natural response of plants aimed at survival.

Table 3. Anatomical Characteristics of the Leaf Epidermis of *Taraxacum officinale* Wigg.

The studied characteristics	Lower epidermis		Upper epidermis	
	Control plot	Experimental plot	Control plot	Experimental plot
Number of cells per 1mm^2	978.80± 24.32	924.45± 16.23	1042.37± 25.62	940.44± 20.08
Number of stomata in 1mm^2	142.02±1.29	125.01±1.34*	81.01±1.14	60.02±0.82*
Stomata length, µm	24.36±0.47	26.12±0.58	23.65±0.52	24.28±0.46
Width of stomata, µm	19.32±0.41	20.54±0.67	17.93±0.36	18.44±0.92
Stomatal index, %	12.67±0.25	11.87±0.11	7.21±0.28	6.21±0.36*

Note: marked with a * are significant differences from the control at $p<0.05$

There is evidence in the literature that the low frequency of stomata combined with their large size contributes to more effective water exchange control (Ceulemans et al. 1978; Bissing 1982). Our findings are also consistent with the results of 2015. Krokhmal (2015) who found that *C. sibirica* adapts to harsh growing conditions at the level of rosette leaves by reducing the number of stomata and increasing their size.

In the conditions of the rock dump, the common dandelion has a fundamentally different system of reliable correlations between anatomical and morphological characteristics in comparison with the plants of the control plot (Table 4). This is manifested as an increase in the total number of correlations, being to a greater extent due to positive correlations.

Thus, the dandelion growing in the conditions of the dump shows close correlation between the thickness of the upper and lower epidermis (+0.84); the mesophyll thickness is positively correlated with the width of the cells and number of stomata of the lower epidermis (+0.84, +0.86, respectively), thickness of the lower epidermis is positively correlated with the length of stomata of the lower epidermis (+0.81) and negatively – with the width of the stomata of the upper epidermis (-0.87); there is close negative relationship between the number of cells of the upper epidermis and the number of cells of the lower epidermis (-0.89) and positive correlation with length of stomata of the lower epidermis (+0.81). The number of cells of the lower epidermis is in a close negative relationship to the length of the upper epidermis stomata (-0.97) and a positive relationship to the stomatal index of the lower epidermis (+0.86). There is a direct positive relationship between the number of stomata of the upper and lower epidermis (+0.82)

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(Table 4).

Table 4. Correlations between Anatomic Characteristics of the Leaves of *Taraxacum officinale* Wigg.

Correlations between the studied characteristics	Significant correlations (r), n=150, p<0,05	
	Control plot	**Experimental plot**
Leaf thickness – width of LE stomata	-0.83	–
LE thickness – UE thickness	–	+0.84
LE thickness – mesophyll thickness	+0.89	–
UE thickness – width of UE stomata	–	+0.97
Mesophyll thickness – number of LE cells	+0.84	–
Mesophyll thickness – width of LE cells	–	+0.84
Mesophyll thickness – number of LE stomata	–	+0.86
LE thickness – width of UE stomata	–	-0.87
LE thickness – length of LE stomata	–	+0.81
Number of UE cells – number of LE cells	–	-0.89
Number of UE cells – number of UE stomata	-0.94	–
Number of UE cells – LE stomatal index	+0.96	–
Number of UE cells – length of LE stomata	–	+0.81
Number of UE stomata – LE stomatal index	+0.96	–
Number of UE stomata – number of LE stomata	–	+0.82
Number of LE cells – length of the UE stomata	–	-0.97
Number of LE cells – LE stomatal index	–	+0.86
Width of the UE stomata – UE stomatal index	+0.86	–
Total correlations:	**7**	**11**
r^+/r^-	**3.5**	**2.66**

Note: UE is the upper epidermis, LE is the lower epidermis

Positive correlations are known to control the development of biosystems and occur during periods critical for the organism. Therefore, a coordinated increase in the number of correlations and a higher proportion of positive correlations between the anatomical characteristics of the common dandelion leaf can be viewed as a specific response aimed at survival and stable existence in the conditions of a rock dump.

When studying hortobiont arthropods at the Yuzhny dump, it was found that their population density was on average 6.5 times significantly higher compared to the control zone (Table 5).
Table 5.

Table 5. The Population Density of Hortobiont Arthropods at the Kedrovsky Coal Mine and at the Control Plot, Specimen/m^2

Group of arthropods	Control plot	Experimental plot
Arachnida	0.17±0.04	0.68±0.14
Ectognatha	4.14±0.53	29.31±5.47
Total arthropods	4.31±0.54	29.99±5.46

The taxonomic structure of hortobionts is formed by representatives of two classes of arthropods: Arachnida and Insecta-Ectognatha.

The proportion of Arachnida in the total structure of hortobionts on the dump was 3.9%, and at the control plot – 2.3% of the total number of arthropods. Arachnida were mainly represented by predatory zoophages – the order Aranei (on average, 98.7% of the total number of Arachnida collected). The most numerous were Arachnida of the family Linyphiidae (47.8% on the dump and 52.5% at the control plot of the total number of all Arachnida collected). Arachnida of this family are eurytopic, which allows them to populate most terrestrial ecosystems and play a significant role in them. Arachnida of the family Linyphiidae are active daytime predators; their trophic spectrum includes a variety of phytophagous and blood-sucking insects.

Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 1, 2021, Pages. 4713 - 4725

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Among the other representatives of Arachnida, the order Opiliones accounts for no more than 1.2%. Ticks (Acariformes) were found only occasionally.

The basis of the hortobiont complex consists of insects of the class Insecta-Ectognatha, which account for 96.17% of the total arthropod collected on the dump, and 97.7% of those collected at the control plot. It should be noted that the average population density of insects on the dump (29.31 specimens/m^2) was significantly higher than the number obtained for the control zone (4.14 specimens/m^2).

The findings on differences in the population density of hortobiont insects are interesting in that the studied coal mine dump shows a change in environmental conditions – the degree of xeromorphism and oligotrophy increases. Hortobionts respond to these changes sharply by increasing their population density. Similar changes were described in Yakutia for meadows of varying degrees of moisture content. It was noted that the greatest abundance and biomass of arthropods in the herb layer is observed in xerophytic meadows with extremely low phytoproductivity (Vinokurov et al. 1988). Researchers believe that in conditions of low temperatures in Siberia, insects find optimal living conditions in the most xerophytic stations, among which are well-warmed dumps of a coal mine. This is especially evident on young dumps aged 7–10 years, characterized by the lowest projective cover and low content of soil moisture and air at the soil surface.

Hortobionts were found to include insects of 9 orders: Diptera, Heteroptera, Hymenoptera, Homoptera, Coleoptera, Orthoptera, Thysanoptera, Neuroptera and Lepidoptera (Table 6). The first five orders are numerically most dominant. They account for an average of 92.1% of the total number of insects collected on the dump and for 94.2% collected in the control zone. The main increase in the number of hortobionts on the rock dump was observed in Diptera and Hemiptera (Fig. 3).

Representatives of the order Diptera significantly dominated in all research areas – both at the mine and at the control plot. Of these, grass flies (Chloropidae) are especially numerous, accounting for an average of 67.9% of all Diptera on the dump, and for 47.5% – in the control zone.

Table 6. Population density of hortobiont insects on the dump of the Kedrovsky coal mine and in the control area, specimen/m^2

Group of insects	Control plot	Experimental plot
Orthoptera	–	0.05±0.02
Homoptera	0.29±0.11	2.72±0.57
Heteroptera	0.79±0.29	6.25±1.42
Thysanoptera	–	1.61±0.94
Coleoptera	0.91±0.15	2.03±0.29
Neuroptera	0.03±0.01	0.07±0.03
Lepidoptera	0.04±0.01	0.12±0.07
Hymenoptera	0.69±0.15	2.96±0.55
Diptera	1.22±0.23	13.02±3.55
Total insects	4.14±0.53	29.31±5.47

These insects inhabit almost all landscapes and are dominant in many open habitats; in ecosystems they are the primary consumers of monocotyledons, mainly grasses and sedges (Narchuk 2005).

Of the hemipterous insects (order Heteroptera), the most dominant were Miridae, whose population density averaged 2.58 specimen/m2 and 41.3% of the total number of Heteroptera collected on the dump, and 0.55 and 69.8%, respectively, of the total number of Heteroptera collected at the control plot. In addition to Diptera (grass flies), Hemiptera (Miridae), other frequently observed hortobionts were other groups of phytophages – species that feed on plants: Coleoptera (weevils, leaf beetles), Homoptera (whiteflies, cicadas, aphids), etc.

Leaf-eating and leaf-sucking phytophages (whiteflies, cicadas, and herbivorous bugs) predominated. Predatory zoophages include Coccinellidae, the ground beetles, Staphylini, predatory bugs and ants.
The dependence of anatomical and morphological characteristics of Taraxacum officinale Wigg leaves and population densities of various groups of hortobiont arthropods on atmospheric emissions in the territory of the rock dump was studied (Tables 5, 6).

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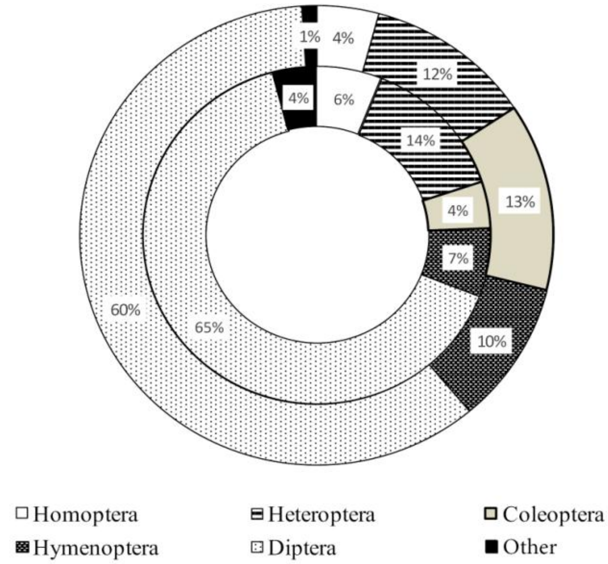

Figure 3. The Ratio of the Main Taxonomic Groups of Arthropods on the Dump of the Kedrovsky Mine (Inner Circle) and at the Control Plot (Outer Circle), %

The results of the correlation analysis showed that the zoological component is sensitive to a wider range of studied air pollutants in comparison with the anatomical and morphological characteristics of *Taraxacum officinale* Wigg leaves. Anatomical and morphological characteristics of the assimilation apparatus of the common dandelion significantly correlate with the complex air quality index (AQI) and dust deposition (Table 7). In particular, the leaf area, the thickness of the upper and lower epidermis, the number of cells and stomata in 1 mm^2 of the lower and upper epidermis negatively correlate with the AQI index; while positive correlations are formed between the AQI and such characteristics as: leaf thickness, mesophyll thickness, length and width of the stomata of the lower and upper epidermis; the number of stomata in 1 mm^2 and the stomatal index of the upper epidermis is in a negative relation to the amount of dust deposition.

Table 7. Significant Correlations between Anatomical and Morphological Characteristics of *Taraxacum officinale* Wigg Leaves and Indices of the Long-Term Impact of Atmospheric Emissions on the Territory of the Rock Dump

Correlations between the studied characteristics	**Significant correlations (r), n=10, p<0,05**
AQI – leaf area	-0.68
AQI – leaf thickness	+0.75
AQI – thickness of the upper epidermis	-0.69
QI – thickness of the lower epidermis	-0.70
KP – mesophyll thickness	+0.74
AQI – number of cells in 1 mm^2 of the lower epidermis	-0.69
AQI – number of stomata in 1 mm^2 of the lower epidermis	-0.72
AQI – length of stomata of the lower epidermis	+0.70
AQI – width of stomata of the lower epidermis	+0.70
AQI – number of cells in 1 mm^2 of the upper epidermis	-0.70
AQI – number of stomata in 1 mm^2 of the upper epidermis	-0.76
AQI – length of stomata of the upper epidermis	+0.71
AQI – width of stomata of the upper epidermis	+0.70
Dust deposition – number of stomata in 1 mm^2 of the upper epidermis	-0.81
Dust deposition – stomatal index of the upper epidermis	-0.75

The population density of some groups of hortobiont arthropods (hortobiont insects, Hemiptera and Hymenoptera) correlates significantly with a wider range of atmospheric pollutants – the complex air quality index (AQI), the dust, nitrate and sulfate deposition (Table 8). Among the hortobiont groups that show significant correlations with the impact of atmospheric emissions, the most sensitive to changes in the environmental conditions of biotopes were Hymenoptera.

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Table 8. Significant Correlations between the Population Density of Hortobiont Arthropods and Indices of Long-Term Impact of Atmospheric Emissions on the Territory of the Rock Dump

Correlations between the studied characteristics	**Significant correlations (r), n=20, p<0,05**
AQI – population density of hortobiont insects, specimen/m^2	+0.47
AQI – population density of Hemiptera, specimen/m^2	+0.47
AQI – population density of Hymenoptera, specimen/m^2	+0.79
Dust deposition – population density of hortobiont insects, specimen/m^2	+0.45
Dust deposition – population density of Hymenoptera, specimen/m^2	+0.81
Nitrate deposition – population density of hortobiont insects, specimen/m^2	+0.49
Nitrate deposition – population density of Hemiptera, specimen/m^2	+0.49
Nitrate deposition – population density of Hymenoptera, specimen/m^2	+0.80
Sulfate deposition – population density of hortobiont insects, specimen/m^2	+0.49
Sulfate deposition – population density of Hemiptera, specimen/m^2	+0.49
Sulfate deposition – population density of Hymenoptera, specimen/m^2	+0.80

Positive correlations are known to control the development of biosystems and occur during periods critical for the organism. The formation of significant correlations (mostly positive) between air quality indices and anatomical and morphological features of the leaf of the common dandelion, as well as the population density of some groups of hortobiont arthropods (hortobiont insects, Hemiptera and Hymenoptera), can be viewed as a specific response aimed at survival and stable existence of the components of the biocenosis in the conditions of a rock dump.

Conclusion

We have studied adaptive responses of herbaceous plants as exemplified by *Taraxacum officinale* Wigg. and hortobiont arthropods in the formation of biocenoses on rock dumps of the Kedrovsky opencast coal mine in the Kemerovo region. Distinctive environmental conditions of the rock dump of the Kedrovsky coal mine cause morphological and anatomical changes in the leaves of *Taraxacum officinale* Wigg. It was shown that the responses in the conditions of the rock dump are:

- at the level of leaf morphology –reduction of the average leaf area, thickening of leaf blades, a trend towards reduction of the number of leaves in the rosette.
- at the level of anatomical structure – a significant increase in the mesophyll thickness, a trend towards reduction of the thickness of the upper and lower epidermis, reduction of the number of cells in 1 mm^2 and an increase in size of stomata in the tissues of the lower and upper epidermis, reduction of the number of stomata per 1 mm^2, reduction of the stomatal index of the upper epidermis.

In the conditions of the rock dump, *Taraxacum officinale* Wigg. has a fundamentally different system of reliable correlations between anatomical and morphological characteristics in comparison with the plants of the control plot. This is manifested as an increase in the total number of correlations, being to a greater extent due to positive correlations, which are known to control the development of biosystems and occur during periods critical for the organism.

In the transformed conditions of the rock dump, distinctive communities of hortobiont arthropods are formed, whose basis is insects of the class Insecta-Ectognatha (96.17 % of the total number of arthropods collected, 97.7% – of the number collected at the control plot). It should be noted that the average population density of insects on the dump (29.31 specimens/m^2) is significantly higher than the number obtained for the control plot (4.14 specimens/m^2). This is due to the formation of optimal conditions for insects on the rock dump – an increase in the humidity of biotopes under low temperatures typical for Siberia, which is especially pronounced in the forest zone where the Kedrovsky mine is located.

Among hortobionts, Arachnida were mainly represented by predatory zoophages – the order Aranei (on average, 98.7% of the total number of Arachnida collected).

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The dominant group of hortobionts –insects – includes 9 orders (Homoptera, Heteroptera, Coleoptera, Hymenoptera, Diptera, Orthoptera, Thysanoptera, Neuroptera, Lepidoptera). The greatest change in population density on the rock dump was observed in two dominant orders – Diptera and Hemiptera. Of the order of Diptera, the most numerous are grass flies (Chloropidae accounting for an average of 67.9% of all Diptera on the dump, and for 47.5% – in the control zone.

The herbage on the rock dump is mainly populated by phytophagous insects – leaf-eating and leaf-sucking phytophages. Predators include Coleoptera (Coccinellidae, the ground beetles, Staphylini), predatory bugs and ants.
The dependence of anatomical and morphological characteristics of *Taraxacum officinale* Wigg leaves and population densities of various groups of hortobiont arthropods on atmospheric emissions in the territory of the rock dump was studied. The results of the correlation analysis showed that the zoological component is sensitive to a wider range of studied air pollutants in comparison with the anatomical and morphological characteristics of *Taraxacum officinale* Wigg leaves.

Anatomical and morphological characteristics of the assimilation apparatus of the common dandelion significantly correlate with the complex air quality index (AQI) and dust deposition:

- leaf area, thickness of the upper and lower epidermis, the number of cells and stomata in 1 mm^2 of the lower and upper epidermis negatively correlate with the AQI;
- leaf thickness, mesophyll thickness, length and width of the stomata of the lower and upper epidermis positively correlate with AQI.
- the number of stomata in 1 mm^2 and the stomatal index of the upper epidermis is in a negative relationship to the amount of dust deposition.

The population density of some groups of hortobiont arthropods (hortobiont insects, Hemiptera and Hymenoptera) correlates significantly with a wider range of atmospheric pollutants – the complex air quality index (AQI), the dust, nitrate and sulfate deposition.

Among the hortobiont groups that show significant correlations with the impact of atmospheric emissions, the most sensitive to changes in the environmental conditions of biotopes were Hymenoptera.

Positive correlations are known to control the development of biosystems and occur during periods critical for the organism. The formation of significant correlations (mostly positive) between air quality indices and anatomical and morphological features of the leaf of the common dandelion, as well as the population density of some groups of hortobiont arthropods (hortobiont insects, Hemiptera and Hymenoptera), can be viewed as a specific response aimed at survival and stable existence of the components of the biocenosis in the conditions of a rock dump.

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