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Carabid Beetle (Coleoptera: Carabidae) Response to Soil Properties of Urban Wastelands in Warsaw, Poland

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Abstract: Urban wasteland is of special interest to city planners. However, to integrate such areas into city space management with consideration of nature conservation aspects, a sound assessment of their ecological potential is necessary. The aim of this paper was to analyze whether carabid beetle assemblages of the wastelands are affected by soil parameters, particularly trace element contamination. Therefore, we studied the carabid fauna in relation to selected soil parameters on 56 ampling plots situated in 24 wastelands located in the city of Warsaw (Poland). The results have confirmed our assumptions that the number of species, as well as the number of individual carabid beetles, are negatively affected by an increasing amount of pollutants in the soil. Particularly, the trace elements Pb, Cu, and Cd showed a significantly negative impact. The results are of value when it comes to the use of urban wastelands in the context of sustainable city development. Future use of urban wastelands will be faced with trade-offs between the use for public interests (e.g., housing space) and ecological interests. Phytoremediation and entomoremediation may be included in decontamination measures. The results of studies, such as the one conducted by us, may help to select the respective wastelands for certain purposes.

Keywords: Carabidae; species richness; abundance; soil parameters; urban wasteland; sustainable development; Poland

1. Introduction

Cities are subjected to permanent economic, social, and political changes, which influence the transformation of spatial urban structures [1]. With a rapid increase in urban population, environmental, social, and economic challenges are growing as well. Currently, cities are being redesigned to become more sustainable [2]. However, sustainable management of urban space is a complex task that requires a many-sided approach. Researchers [3] have emphasized that there is a need for a framework for creating new policies and encouraging more strategically organized efforts in sustainable environmental planning.

A major dilemma regarding big cities is that, on the one hand, their population density is very high and inhabitants demand space for many different purposes, such as new housing areas, space for recreation, or economic purposes but, on the other hand, vacant natural areas are scarce [4]. Therefore, urban wasteland (abandoned and unmaintained areas in a city [5]) is of special interest for city planners [1,5]. The significance of urban wasteland, including urban post-industrial areas, for nature conservation, has been discussed for decades [6–8]. One of the concepts in line with this objective is to use them as wilderness areas, characterized by a high level of self-regulation in ecosystem processes [9].

However, to integrate urban wastelands into city space management with consideration of nature conservation aspects, a sound assessment of their ecological potential is necessary. A key factor of such areas is their soil properties, which are often modified in cities, and are of very high importance for numerous plants and animals. The soil of urban areas is physically, chemically, and biologically altered, has a reduced share of organic matter and nutrients, a high content of alien materials, and compaction resulting in structural degradation [10]. The majority of carabid beetles (Carabidae) species show epigeic activity [11]. Carabid beetles are known to be sensitive to human-altered abiotic conditions [12,13] and can be easily and cost-effectively sampled [14], which makes them suitable indicators for soil contamination [12,15]. Several studies have been carried out dealing with the response of these beetles to soil contamination. Elevated levels of different pollutants such as Zn, Cu, and Ni resulted, for example, in decreased species richness and biomass [16,17], as well as reduced larval survival [18]. Exposure to elevated Cu levels during the larval stage altered locomotory behavior in *Poecilus cupreus* [19]. Agrochemical treatment of sites may contribute to increased amounts of trace elements in the soil, which are accumulated by individual carabid species [20]. All these studies have indicated that carabid beetles are suitable indicators regarding soil contamination.

Warsaw is the biggest city in Poland. It suffers from a rapid increase in population and strong urbanization pressure [5]. In 2020, Warsaw had a population density of approximately 3372 residents per square kilometer [21]. In the frame of an interdisciplinary research project dealing with urban wasteland in the city of Warsaw, soil parameters and carabid beetles were studied. The aim of this paper was to analyze whether carabid beetle assemblages of the wastelands are affected by soil parameters, particularly, by trace element contamination. Our hypothesis was that both the number of species, as well as the number of individual carabid beetles, are negatively affected by an increasing amount of pollutants in the soil. The results are to be discussed in the context of nature conservation as an element of sustainable city development.

2. Materials and Methods

2.1. Study Areas and Sampling Plots

In order to elaborate data on carabid beetles and soil parameters, 24 wastelands (Figure 1) were included in the presented study. At each site, based on vegetation characteristics, characteristic vegetation units were identified, and selected soil parameters were elaborated, in each of which independent sampling plots for the collection of carabid beetles were established. Based on the obtained results, sampling plots were assigned to the respective vegetation units and soil parameters. As a result, 56 sampling plots were chosen for the analyses (Table 1).

With respect to carabid beetles, it is generally observed that young stages of succession exhibit a high number of species and individuals, compared with advanced stages of succession [22–24]. In order to be able to exclude a bias concerning this matter, each sampling plot was assigned to either a young or advanced stage of succession (Table 1).

Table 1. Phytosociological characterization and the stage of succession of the sampling plots, as well as numbers of collected carabid beetle species and individuals (100 trap-days). The first number of the sampling plots denotes the area (numbers of the areas, as in Figure 1), the second number is the respective sampling plot in the area.

Sampling Plot	Phytosociological Units	Stage of Succession	Species	Individuals
1-1	Regenerative woodland (*Populus* × *canescens* association)	Advanced	1	0.39
1-2	Grassland (*Calamagrostietum epigeji* Juraszek 1928)	Early	10	8.98
1-3	Grassland *(Festuca rubra,* association on a slope)	Advanced	7	10.16
1-4	Rushes (*Phragmition* Koch 1926)	Early	3	2.22
1-5	Regenerative woodland (*Quercus rubra*, *Tilia cordata* association)	Advanced	6	3.91
2-1	Regenerative woodland (*Quercus robur, Betula pendula* association)	Advanced	11	50.78
2-2	Regenerative woodland (*Betula pendula, Populus tremula* association)	Advanced	7	7.81
2-3	Bushes (*Solidago gigantea* association)	Early	23	66.80
3-1	Grassland (*Lolio-Cynosuretum* R.Tx. 1937)	Early	5	8.62
3-2	Grassland (*Dactylis glomerata* association)	Early	10	53.73
3-3	Bushes (*Prunus cerasifera* association)	Early	14	12.31
4-1	Eegenerative woodland (*Salix caprea, Betula pendula* association)	Advanced	7	6.30
4-2	Regenerative woodland (*Acer platanoides, Acer negundo* association)	Early	7	5.51
4-3	Herbs (*Artemisietea* Lohm., Prsg et R. Tx. in R. Tx. 1950)	Early	12	46.85
5-1	Regenerative woodland (*Acer negundo* association)	Early	7	10.23
5-2	Bushes (*Solidago gigantea* association)	Early	11	28.41
6-1	Tree coverage of *Prunus cerasifera, Acer pseudoplatanus*	Advanced	8	17.29
6-2	Grassland (*Arrhenatherion elatioris* (Br.-Bl. 1925) Koch 1926)	Early	13	30.45
6-3	Grassland (*Lolio-Polygonetum* Br-Bl. 1930 em. Lohm. 1975)	Early	19	153.38
7-1	Grassland (*Lolio-Cynosuretum* R.Tx. 1937)	Early	10	124.81
7-2	Regenerative woodland (*Acer negundo* association)	Advanced	12	16.41
8-1	Regenerative woodland (*Acer negundo* association)	Advanced	11	14.02
8-2	Herbs (*Artemisietea* Lohm., Prsg et R. Tx. in R. Tx. 1950)	Early	8	12.88
9-1	Regenerative woodlands (*Tilia cordata, Acer platanoides* association)	Advanced	6	6.53
9-2	EGrassland (*Lolio-Cynosuretum* R.Tx. 1937)	Early	14	71.90
10-1	Regenerative woodland (*Populus* × *canescens* association)	Early	13	78.41
10-2	Grassland (*Lolio-Cynosuretum* R.Tx. 1937)	Early	10	35.35
10-3	Grassland (*Calamagrostietum epigeji* Juraszek 1928)	Early	11	38.38
11-1	Bushes (*Prunus cerasifera* association)	Early	6	3.70
11-2	Bushes (*Corylus avellana* association)	Early	7	7.41
12-1	Bushes (*Solidago gigantea* association)	Early	9	19.70
12-2	Regenerative woodland (*Acer negundo* association)	Advanced	10	9.09
12-3	Regenerative woodland (*Populus tremula, Acer negundo* association)	Advanced	5	6.82

Table 1. *Cont.*

Sampling Plot	Phytosociological Units	Stage of Succession	Species	Individuals
13-1	Regenerative woodlands (*Populus nigra-P.* × *canescens* association)	Advanced	10	12.88
13-2	Bushes (*Cornus sanguinea* association)	Early	10	6.44
14-1	Regenerative woodland (*Quercus rubra*, *Acer platanoides* association)	Advanced	10	9.84
14-2	Regenerative woodland (*Betula pendula*, *Agrostis capillaris* association)	Advanced	6	14.57
15-1	Regenerative woodland (*Acer negundo* association)	Early	3	1.10
16-1	Regenerative woodland (*Populus* × *canescens* association)	Early	0	0.00
16-2	Regenerative woodland (*Acer negundo* association)	Early	0	0.00
17-1	Regenerative woodland (*Robinia pseudoacacia* association)	Advanced	20	42.16
17-2	Grassland (*Lolio-Cynosuretum* R.Tx. 1937)	Early	12	14.18
17-3	Regenerative woodland (*Tilia cordata* association)	Advanced	14	10.07
17-4	Regenerative woodland (*Tilia cordata* association)	Advanced	21	41.79
17-5	Woodland (*Populus* × *canescens* association)	Advanced	21	63.06
18-1	Woodland (*Acer negundo* association)	Early	19	20.08
19-1	Regenerative woodlands (*Salicetum albo-fragilis* R.Tx. 1955)	Advanced	35	187.50
20-1	Regenerative woodlands (*Salicetum albo-fragilis* R.Tx. 1955)	Early	18	44.92
21-1	Regenerative woodlands (*Salicetum albo-fragilis* R.Tx. 1955)	Early	21	53.91
21-2	Woodland (*Populetum albae* Br.-Bl. 1931)	Early	14	48.05
22-1	Regenerative woodlands (*Salicetum albo-fragilis* R.Tx. 1955)	Advanced	17	23.48
22-2	Woodland (*Populetum albae* Br.-Bl. 1931)	Advanced	10	9.09
23-1	Grassland (*Lolio-Cynosuretum* R.Tx. 1937)	Early	6	19.07
23-2	Woodland (*Populus* × *canescens* association)	Advanced	8	5.56
24-1	Regenerative woodland (*Quercus robur, Tilia cordata* association)	Advanced	13	35.98
24-2	Regenerative woodland (*Acer platanoides*, *Robinia pseudoacacia* association)	Advanced	10	11.36

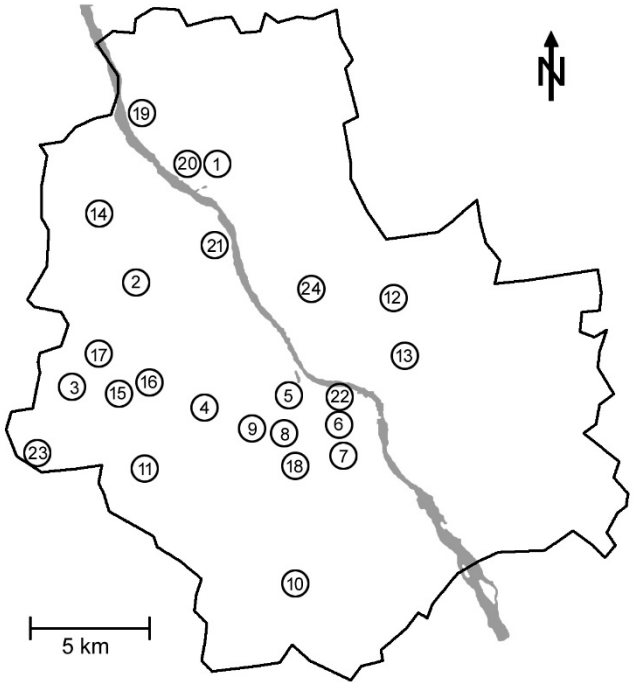

Figure 1. Location of the studied wastelands (1–24) in Warsaw (Poland).

2.2. Field and Laboratory Methods

Carabid beetles were collected using pitfall traps [25]. At each sampling plot, two traps were installed with a maximum distance of 3 m from each other. The traps were glass jars topped with a funnel (upper diameter of about 10 cm), set flush with the soil surface. A roof was suspended a few centimeters above the funnel and ethylene glycol was used as a killing agent and preservative. The traps were placed at least 15 m from the edge of the plots. However, this was not possible in every case, due to the shape of some plots (1-2, 1-3, 1-4, 2-3, 3-3, 4-1, 9-1, 12-1, 12-2, 13-2, 15-1, 17-5). Carabids were sampled from mid-May to late September in 2018. The traps were controlled for proper performance during some field visits, and exchanged in July.

Determination and nomenclature of the individuals collected were carried out in accordance with the literature [26]. All individuals were identified to the species level by the first author. Voucher specimens of each species were deposited in a collection of the first author at the Warsaw University of Life Sciences—SGGW. We characterized the species with respect to the functional traits, habitat preference, trophic specialization, and breeding type, based on the literature [11,26–31].

Soil samples were picked with the use of an Egner stick, up to a depth of 20 cm. The soil was sampled in triplicates at each wasteland (1–24), with an area of 5000–10,000 m^2. A single replicate was a pooled sample of 20–25 individual ones. To exclude any variation in the physical and chemical properties of the soil, the averages obtained for the whole area represented all plots within the given area. The soil samples for pH, electrical conductivity (EC), soil water content (SOC), and organic matter (Org) were collected in mid-June (Term I), July/August (Term II), and mid-September (Term III), while the determination of trace element concentrations occurred once in mid-September.

Soil samples were stored in a refrigerator prior to analysis for up to 24 h. A quantitative analysis of the content of selected trace elements (TE) (Cu, Zn, Pb, Cd, Cr, Ni) in the soil was carried out at the end of September 2018. The soil samples were mineralized in a mixture of concentrated HNO_3 and $HClO_4$, and then the TE were analyzed by atomic absorption spectrometry (AAS) (Perkin Elmer AAnalyst 800). The analyses were performed in the accredited laboratory of the National Chemical-Agricultural Station in Warsaw, in accordance with the station's research procedure 27 (6th edition, dated 14 February 2011). The analysis of soil pH and electrical conductivity (EC, $mS \cdot cm^{-1}$) was carried out as follows: soil samples were treated with distilled water in a 1:2 ratio and then

analyzed with the use of a pH Meter/Conductometer (inoLab, Conbest). In order to analyze organic matter (% of dry matter), the soil samples were heated in a preheated muffle furnace (P330, Nabertherm) for 5 h at 450 °C, and the organic matter content was calculated as a difference between the initial and final sample weight. The soil water content (SWC) (% *w*/*w*) was determined by the gravimetric method. The soil samples were dried in a convection oven at 105 °C, and water content was calculated as the ratio of water weight to the weight of air-dried soil.

The maximum permissible levels of trace elements in light soils ($mg \cdot dm^{-3}$) were taken from the Polish national regulation, the Decree of the Minister of Environment of 1 September 2016 [32].

2.3. Statistical Methods

For each sampling plot, the data of the two traps and the sampling periods were pooled and the total number of species was calculated. Since the collecting period differed between the sampling plots by some days, the number of individuals was adjusted to 100 trapping days per one trap (100 trap-days) for each sampling plot.

In the first step, the data were bias tested regarding the species numbers and numbers of individuals due to stages of succession. In order to do so, the species numbers and numbers of individuals (100 trap-days) were compared between the young stages of succession and the advanced ones. As normal distribution was rejected by Kolmogorov–Smirnov tests, we used a Mann–Whitney U test with IBM SPSS Statistics, version 25.

Canoco for Windows 4.56 [33,34] was used to carry out nonparametric multivariate regression analyses on species numbers and numbers of individuals, using the following soil parameters selected as independent variables: trace elements (TE $mg \cdot kg^{-1}$ dry matter: Pb, Cd, Ni, Cr, Cu, Zn), soil pH (pH I—Term I, pH II—Term II, pH III—Term III), electrical conductivity (EC I—Term I, EC II—Term II, EC III—Term III), organic matter (Org I—Term I, Org II—Term II, Org III—Term III), and soil water content (SWC I—Term I, SWC II—Term II, SWC III—Term III). The significance of the individual variables was tested using Monte Carlo permutation tests (unrestricted, 1999 permutations), first, for each variable separately in order to study the variance explained by each variable separately, and then using an automatic forward selection of variables (reduced model) in order to study additionally explained variance after already adding variables to the ordination model [34,35].

Canoco for Windows 4.56 was also used to conduct a constraint ordination analysis in order to determine the major pattern in variation in relationship with the environmental factors. Detrended Canonical Correspondence Analysis (DCCA) was first used to select the appropriate statistical model based on the longest gradient [35] and then Canonical Correspondence Analysis (CCA) was carried out. Dominance values (percentage share of the respective species in a sample) for the carabid species at the different sites were used. The analyses were performed using inter-sample distance scaling, Hill's scaling, and unweighted data for each of the species. Since dominance values were used, the data were not transformed.

3. Results

From the 56 sampling plots altogether, 3994 individual carabid beetles belonging to 76 species were collected (Table S1). Both numbers of species and numbers of individuals varied strongly among the sampling plots (Table 1). The highest number of both species and individuals was collected in a plot with regenerative woodlands of *Salicetum albo-fragilis* with an advanced stage of succession (Sampling Plot 19-1). In contrast, no beetles were collected in a plot with regenerative woodland with *Populus* × *canescens* association and a regenerative woodland with *Acer negundo* association, both located in the same study area (Sampling Plots 16-1 and 16-2).

For both the numbers of species (Mann–Whitney U test, $p = 0.735$) and individuals per 100 trap-days (Mann–Whitney U test, $p = 0.175$) the Mann–Whitney U test did not reveal any significant difference, hence, a bias of the data with respect to succession stage could be neglected.

The pH of the soils ranged from 4.12 to 8.5, that is, slightly acidic to alkaline, while the salt concentration ranged from 0.08 to 6.90 mS·cm^{-1} (Appendix A, Table A1). In most wastelands, the salt concentration was relatively low and within the concentration range typical of urban soils in recreational locations (parks, lawns). Within several locations, a high variability of this parameter was noted. The highest electrical conductivity was recorded in the soils sampled from Plots 8-1 and 8-2.

The content of organic matter ranged between 0.44% and 19.61% dry matter. The lowest actual soil moisture (% *w*/*w*) was noted in Study Area 13, whereas the highest one in Study Area 8.

The obtained results of trace element concentrations (Appendix A, Table A1) have confirmed that the permissible limits of trace elements in the topsoil were exceeded in light soils of agricultural areas by Pb, Cu, and Zn, only in some wastelands. Concentrations of Pb were above the limits in Study Areas 16 and 12, Cu in Study Areas 11 and 12, and Zn in Study Areas 9 and 15. Trace concentrations of Pb were also found in Study Areas 1, 10, 19, and 22, while Cu was in Study Area 22. The least contaminated area among the studied wastelands was Study Area 10, where the only recorded trace concentrations were of Pb, Ni, and Cr. For the remaining three elements (Cd, Cu, Zn), the concentrations did not exceed the limits even for protected areas.

When testing the impact of the soil parameters on the number of carabid species separately, Pb and Cu had a significant impact. Using a forward selection of variables, significant results were received for Pb, Cd, Org III, and Cr (Table 2). Regarding the impact of the parameters on the number of collected individual carabid beetles, the variables separately tested revealed a significant impact of Pb. Using a forward selection of variables, besides Pb, the variables Cd and EC II had an additional significant impact (Table 3).

Table 2. Results of Monte Carlo permutation tests of the environmental variables (soil parameters) impact on species numbers, tested separately and using an automatic forward selection of variables (reduced model). Lambda-1—variance explained by the environmental variables separately; Lambda-A—additional variance explained when included in the model using forward selection.

Variable	Tested Separately			Forward Selection		
	Lambda-1	**F**	***p***	**Lambda-A**	**F**	***p***
Pb	0.18	11.868	0.0020	0.18	11.87	0.002
Cu	0.09	5.614	0.0195	0.01	1.69	0.197
SWC I	0.06	3.152	0.0715	0.01	1.73	0.190
pH III	0.04	1.993	0.1745	−0.00	0.05	0.814
Zn	0.04	1.960	0.1560	0.02	1.48	0.242
Org II	0.02	0.967	0.2875	0.04	3.06	0.082
pH I	0.02	0.919	0.3360	0.00	0.82	0.373
Cd	0.01	0.693	0.4100	0.10	7.04	0.011
EC I	0.01	0.519	0.4765	0.05	4.02	0.057
EC II	0.01	0.416	0.4960	0.02	1.26	0.254
Org III	0.01	0.296	0.5765	0.09	9.20	0.004
Cr	0.00	0.246	0.6175	0.05	4.28	0.038
SWC III	0.00	0.094	0.7500	0.01	0.80	0.366
Ni	0.00	0.069	0.7740	−0.00	0.05	0.826
SWC II	0.00	0.021	0.8855	0.01	0.77	0.401
pH II	0.00	0.015	0.9035	0.01	0.63	0.412
EC III	0.00	0.016	0.9035	0.01	0.76	0.373
Org I	0.00	0.014	0.9110	−0.00	0.00	0.945

Table 3. Results of Monte Carlo permutation tests of the environmental variables (soil parameters) impact on numbers of individuals (100 trap-days), tested separately and using an automatic forward selection of variables (reduced model). Lambda-1—variance explained by the environmental variables separately; Lambda-A—additional variance explained when included in the model using forward selection.

Variable	Tested Separately			Forward Selection		
	Lambda-1	**F**	***p***	**Lambda-A**	**F**	***p***
Pb	0.07	4.354	0.0445	0.07	4.35	0.045
Cu	0.06	3.423	0.0525	0.02	1.36	0.258
Cd	0.04	2.392	0.1315	0.12	7.84	0.010
SWC I	0.04	2.249	0.1415	0.02	1.46	0.229
Ni	0.03	1.514	0.2120	0.02	1.82	0.184
EC II	0.03	1.390	0.1995	0.10	7.49	0.014
EC I	0.02	1.327	0.2545	−0.00	0.35	0.545
Org II	0.02	1.304	0.2254	0.04	2.38	0.133
Cr	0.01	0.798	0.3790	0.02	1.17	0.296
Org I	0.01	0.603	0.4735	0.01	1.50	0.216
Org III	0.00	0.274	0.5945	0.01	1.10	0.327
Zn	0.00	0.181	0.6710	0.03	1.85	0.190
pH II	0.00	0.108	0.7405	0.02	2.10	0.155
SWC II	0.00	0.079	0.7760	0.01	1.16	0.290
pH III	0.00	0.077	0.7760	0.03	2.02	0.165
EC III	0.00	0.016	0.9075	0.02	1.25	0.262
pH I	0.00	0.005	0.9455	0.01	1.08	0.299
SWC III	0.00	0.000	1.0000	0.01	1.11	0.301

The first canonical axis of the CCA (Figure 2) explained 5.7% of the variation in species data and 16.4% of that in the species–environment relationship. The second canonical axis explained 3.9% and 11.1%, respectively. Almost all environmental factors pointed to the top left from the origin of the diagram, with the exception of EC I and EC II pointing to the top right, and Cr, SWC I, and SWC III pointing to the bottom left. Sampling plots that best fit into the ordination space located in the left from the origin are 15-1 (top left), and 14-2 and 2-1 (bottom left). All others are located to the right of the origin of the diagram. Species that best fit into the ordination space positively related to the environmental factors are *Stomis pumicatus* and *Licinus depressus* (Pb, Zn, EC III), *Pterostichus melanarius* (Cr, SWC I, SWC III) and *Harpalus rufipes*, *Harpalus affinis,* and *Calathus melanocephapus* (EC I, EC II). However, a majority of species that best fit into the ordination space is rather negatively related to the environmental factors (*Calathus fuscipes*, *Calathus erratus*, *Syntomus truncatellus*, *Poecilus lepidus*, *Badister peltatus*, *Harpalus anxius*).

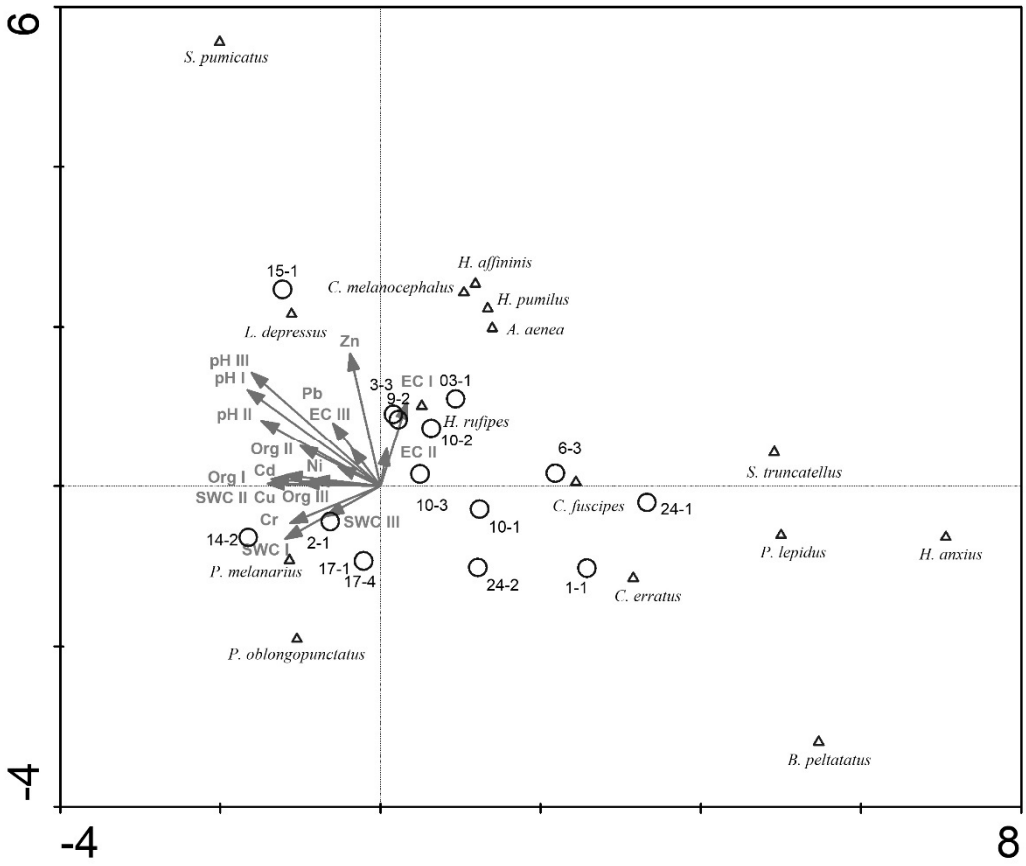

Figure 2. Ordination plot based on Canonical Correspondence Analysis (CCA) for 15 sampling plots (open circles) and 15 species (open triangles) that best fit into the ordination space and environmental variables (arrows). Numbers of sites are listed in Table 1. SWC: Soil Water Content; EC: Electrical Conductivity; Org: Organic Matter.

4. Discussion

The results have confirmed our assumptions that numbers of species, as well as numbers of carabid beetle individuals, are negatively affected by increasing concentrations of trace elements in the soil. Particularly, the trace elements Pb, Cu, and Cd showed a statistically significant negative impact.

Our study has revealed some clear differences in soil parameters, including the trace elements. When it comes to the degree of soil pollution at an individual locality, historical aspects, as well as the present situation of the study areas and sampling plots, are crucial. For example, Study Areas 15 and 16, which showed high pollutions with respect to some trace elements, are closely located to railway tracks and a cement plant [36].

Carabid beetles are known to react to soil conditions [11], as also shown by a significant effect of organic matter (Org III) and electrical conductivity (EC II). Particularly, organic matter plays an important role, because the organic layer plays an essential role for many species, for instance, as a refugee after habitat disturbances, or as a place for foraging or laying eggs [37–39].

The effects of trace elements on carabid beetles observed by us correspond with the results obtained previously by other researchers [40–42]. They suggested that trace elements in the soil significantly and negatively affect carabids. Carabid beetles are one of the most intensively studied groups of epigeic arthropods regarding their relation to trace element accumulation and their use as a bioindication of environmental pollution. Responses of organisms to trace element pollution are greatly dependent on several factors, such as species, form and concentration of metals, time of exposure, and pH conditions, which are closely related to the bioavailability of metals [43,44]. Furthermore, Cu, Zn, and Mn are micronutrients needed for the growth of organisms, while Cd and Pb are harmful even in small

amounts [45]. The indicatory potential of carabid beetles can manifest itself not only as an absence or presence of species, but also as altered physiological and/or morphological characteristics [46]. These authors had reported severe gut degeneration as a result of Cd, Ni, and Zn pollution; however, the contribution of these metals to the development of the symptom was different. Other studies showed a highly sensitive immune response to environmental pollution in the preimaginal stages [47] and reduced size of individuals collected in polluted areas [48].

How strongly an individual species is affected depends on its autecological characteristics. Undisputedly, feeding habits have an important impact on how much of the toxic substances are accumulated, as demonstrated by researchers [49], especially for Cd. Researchers [16] showed that autumn breeding species seemed to be more sensitive than spring breeders in the case of Zn and Pb pollution. Feeding behavior of the respective species may also be of importance [15]. In our study, however, the CCA (Figure 2) did not reveal a clear distinction with respect to the breeding type or trophic specialization of the species (Table S1). However, the degree of pollution in the respective area can be also relevant. Studies have indicated that in highly polluted habitats, carabid beetles showed a very high accumulation potential for Cd, Pb, and Zn, whereas in habitats of low pollution they were able to regulate the concentration of trace elements in their body via detoxification mechanisms. In conclusion, carabid beetles as entomoremediators may be useful in the decontamination of soils extremely polluted by trace elements [50].

Even if we could reject differences between the study sites with respect to the stage of succession as a bias, other factors might have an influence on numbers of species and individuals, too. Some studies have proven a decrease in species numbers from rural to urban forested sites [51], and accordingly, the location of the sampling plots in the city space might have had some impact. The degree of anthropogenic pressure may also depend on the location of the plots. Toxic pollutants and other environmental factors often show interactions [18]. The combined effect of nickel and chlorpyrifos was temperature-dependent both in the adults and larvae of *Pterostichus oblongopunctatus* [52,53]. Since pitfall traps measure the activity density of the carabids, particularly, numbers of individuals may be also affected by factors influencing their mobility. For example, dense vegetation might impede the movements of carabid beetles ("Raumwiderstand") [54,55]. Locomotory activity also depends on the feeding state of the individuals [56].

Even if the numbers of species and individuals of carabid species in individual sites depend on a complex set of different biotic and abiotic environmental factors, our study has indicated the impact of soil contamination and is in accordance with previously published data. The results also corroborate the usability of carabid beetles as indicators for the environmental impact of soil pollution. Thus, the increased levels of soil pollutants negatively impact the studied areas by both degrading the soil quality itself and causing a reduction of carabid beetle species diversity. The results are of value when it comes to the use of urban wastelands in the context of sustainable city development. Some obvious tasks include solid assessments of contamination and ecological potential, since the reclamation of wastelands demands to take into account natural processes, plants, animals, physical factors, nutrients, and toxicities [57]. Future use of urban wastelands is going to be faced with trade-offs between the use for public interests (e.g., housing space) and ecological interests. Already in the 1990s, the idea of 'rotating wastelands' was discussed, that is, to maintain a certain number of wastelands by building on some wastelands only when new ones appear [58]. A different approach proposes a unifying framework for urban wilderness as a social-ecological system [9]. Researchers [59] raised awareness of the need for a more theoretically nuanced and historically grounded focus on the intersections between urban ecology and culture in the contemporary city. Other researchers [5] emphasized that urban wastelands, after not having been used for many years, have spontaneously generated their own social and natural values, which should be taken into consideration at different levels of planning. In order to increase the potential of the areas, the strategy of phytoremediation, that is, the use of plant species to combat alterations in environmental conditions, can be of interest [60]. Phytoremediation seems to be among the most effective measures in order to restore contaminated areas. As mentioned above,

the carabid beetles themselves may even participate as entomoremediators. Yet, the results of studies, such as the one conducted by us, may help to select the respective wastelands for certain purposes.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/24/10673/s1, Table S1: Numbers of collected carabid beetle individuals (100-trap-days) at the sampling plots including information about functional traits of the species: Habitat preference (o—open habitat species, f—forest species, e—eurytopic species), trophic specialization (hz—hemizoophagous species, sz—small zoophagous species, bz—big zoophagous species) and breeding type (s—spring breeder, a—autumn breeder).

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Appendix A

Table A1. Concentrations of selected trace elements (TE; mg·kg^{-1} dry matter), soil pH, electrical conductivity (EC; mS·cm^{-1}), organic matter (Org, % dry matter) and soil water content (SWC, % *w*/*w*) in the studied wastelands (n = 3).

Sampling Plot	pH I	pH II	pH III	EC I	EC II	EC III	Org I	Org II	Org III	SWC I	SWC II	SWC III	Pb	Cd	Ni	Cr	Cu	Zn
1-1	6.23	6.03	5.48	0.88	0.54	0.10	1.79	2.17	1.60	3.30	7.46	11.08	10.0	0.18	8.0	8.0	5.8	34.8
1-2	6.46	6.20	5.89	0.57	0.52	0.17	3.98	6.13	1.10	2.10	10.10	6.66	10.0	0.18	8.0	8.0	5.8	34.8
1-3	6.46	6.20	5.89	0.57	0.52	0.17	3.98	6.13	1.10	2.10	10.10	6.66	10.0	0.18	8.0	8.0	5.8	34.8
1-4	6.46	6.20	5.89	0.57	0.52	0.17	3.98	6.13	1.10	2.10	10.10	6.66	10.0	0.18	8.0	8.0	5.8	34.8
1-5	7.21	7.07	5.45	0.61	0.63	0.48	2.76	6.69	1.03	1.80	6.54	3.96	10.0	0.18	8.0	8.0	5.8	34.8
2-1	7.03	6.97	7.30	0.38	0.39	0.24	4.29	5.51	2.64	6.00	13.64	11.55	19.7	0.24	8.0	13.2	8.5	47.7
2-2	7.47	6.95	7.89	0.60	0.51	0.28	2.04	6.16	2.18	5.60	14.10	12.00	19.7	0.24	8.0	13.2	8.5	47.7
2-3	7.29	5.53	5.30	0.56	0.14	0.08	3.58	3.97	1.19	4.10	10.95	12.21	19.7	0.24	8.0	13.2	8.5	47.7
3-1	7.7	7.58	7.48	1.42	1.00	1.29	3.04	3.94	3.41	5.10	8.72	7.32	54.8	0.32	8.0	8.0	33.3	259.0
3-2	7.67	7.53	7.72	1.01	1.11	0.75	2.87	5.79	4.03	6.10	8.13	5.31	54.8	0.32	8.0	8.0	33.3	259.0
3-3	7.89	7.60	7.31	1.49	0.72	0.85	3.56	3.01	6.43	4.80	8.95	5.81	54.8	0.32	8.0	8.0	33.3	259.0
4-1	7.25	7.20	7.33	0.96	0.66	1.41	3.25	3.60	7.26	5.00	6.05	11.45	57.8	0.41	15.2	17.1	37.0	273.0
4-2	7.17	7.36	7.15	0.71	0.64	1.13	2.91	4.91	4.04	12.60	10.71	4.31	57.8	0.41	15.2	17.1	37.0	273.0
4-3	7.17	7.36	7.15	0.71	0.64	1.13	2.91	4.91	4.04	12.60	10.71	4.31	57.8	0.41	15.2	17.1	37.0	273.0
5-1	7.04	6.31	7.11	1.29	0.63	0.34	6.68	5.73	10.93	12.70	20.35	15.09	26.4	0.38	25.5	25.9	31.7	140.0
5-2	7.04	6.31	7.11	1.29	0.63	0.34	6.68	5.73	10.93	12.70	20.35	15.09	26.4	0.38	25.5	25.9	31.7	140.0
6-1	7.45	7.82	7.59	1.21	0.57	2.92	3.87	3.03	3.00	6.90	9.87	9.06	15.8	0.28	14.0	16.2	15.8	77.8
6-2	7.47	7.23	7.36	0.82	1.55	6.00	1.94	4.32	5.71	4.60	13.64	9.93	15.8	0.28	14.0	16.2	15.8	77.8
6-3	7.45	7.38	7.42	0.91	2.96	0.75	2.88	2.49	2.56	6.70	11.26	9.28	15.8	0.28	14.0	16.2	15.8	77.8
7-1	6.98	7.13	7.33	1.92	0.33	1.60	7.54	3.36	2.86	16.70	8.05	7.56	30.4	0.61	30.4	27.4	29.9	130.0
7-2	7.23	6.81	6.96	0.63	0.88	0.70	9.40	7.26	6.65	15.00	21.09	13.56	30.4	0.61	30.4	27.4	29.9	130.0
8-1	7.64	7.52	7.52	0.71	4.46	6.90	8.59	19.38	19.61	8.00	27.20	41.11	19.9	0.25	8.0	8.0	12.9	87.8
8-2	7.64	7.52	7.52	0.71	4.46	6.90	8.59	19.38	19.61	8.00	27.20	41.11	19.9	0.25	8.0	8.0	12.9	87.8
9-1	7.39	7.16	6.96	0.82	0.80	0.54	7.35	6.47	7.11	7.80	7.87	21.61	97.8	0.71	14.2	18.7	56.7	495
9-2	7.39	7.16	6.96	0.82	0.80	0.54	7.35	6.47	7.11	7.80	7.87	21.61	97.8	0.71	14.2	18.7	56.7	495
10-1	6.38	5.17	5.04	0.56	0.14	0.30	3.31	4.84	3.73	2.70	3.69	5.81	10.00	0.08	8.0	8.0	3.5	14.9
10-2	7.40	7.19	7.69	1.10	0.86	0.74	3.44	7.57	3.26	3.90	4.14	9.35	10.00	0.08	12.6	12.6	5.9	32.8
10-3	7.5	7.35	7.4	1.09	1.15	0.80	3.44	6.13	6.11	3.90	7.32	10.42	10.00	0.06	8.0	8.0	6.0	26.7

Table A1. *Cont.*

Sampling Plot	pH I	pH II	pH III	EC I	EC II	EC III	Org I	Org II	Org III	SWC I	SWC II	SWC III	Pb	Cd	Ni	Cr	Cu	Zn
11-1	7.9	7.48	7.95	0.46	0.07	1.00	1.96	2.84	0.44	4.30	2.38	11.20	89.3	0.22	8.0	22.3	305.0	126.0
11-2	7.9	7.48	7.95	0.46	0.07	1.00	1.96	2.84	0.44	4.30	2.38	11.20	89.3	0.22	8.0	22.3	305.0	126.0
12-1	6.56	5.8	6.82	0.40	0.12	0.36	6.41	6.13	7.44	8.00	8.28	15.71	119.0	0.27	8.0	8.0	244.0	88.8
12-2	6.56	5.8	6.82	0.40	0.12	0.36	6.41	6.13	7.44	8.00	8.28	15.71	119.0	0.27	8.0	8.0	244.0	88.8
12-3	6.64	6.42	7.26	0.92	0.29	0.27	8.05	7.57	7.06	13.40	17.30	13.92	119.0	0.27	8.0	8.0	244.0	88.8
13-1	7.57	6.36	6.25	1.02	0.17	0.40	5.98	1.75	3.04	5.00	1.63	6.82	40.2	0.20	8.0	8.0	40.6	110.0
13-2	7.57	6.36	6.25	1.02	0.17	0.40	5.98	1.75	3.04	5.00	1.63	6.82	40.2	0.20	8.0	8.0	40.6	110.0
14-1	7.12	7.14	6.00	1.19	1.01	0.14	8.98	7.34	2.79	5.00	4.96	11.05	54.6	0.47	8.0	18.4	42.6	86.7
14-2	7.23	6.82	5.73	0.77	0.60	0.37	5.41	6.55	4.80	4.30	8.38	8.97	54.6	0.47	8.0	18.4	42.6	86.7
15-1	7.64	7.3	8.42	0.84	0.95	1.12	5.39	9.96	4.71	5.30	20.94	10.64	58.9	0.67	17.2	17.6	113.0	321.0
16-1	7.74	7.45	8.50	0.65	0.49	0.38	6.86	5.44	1.77	7.20	16.29	12.13	196.0	0.96	14.5	20.6	131.0	277.0
16-2	7.74	7.45	8.50	2.33	0.58	0.49	6.86	5.44	1.77	7.20	16.29	12.13	196.0	0.96	14.5	20.6	131.0	277.0
17-1	6.28	6.99	6.25	0.60	0.52	0.53	6.30	5.14	5.94	13.10	10.01	10.96	19.6	0.58	12.6	15.9	24.8	114.0
17-2	6.28	6.99	6.25	0.60	0.52	0.53	6.30	5.14	5.94	13.10	10.01	10.96	19.6	0.58	12.6	15.9	24.8	114.0
17-3	6.48	6.25	6.08	0.76	0.20	0.49	5.26	4.42	3.69	10.80	8.73	8.41	19.6	0.58	12.6	15.9	24.8	114.0
17-4	6.28	6.99	6.25	0.60	0.52	0.53	6.30	5.14	5.94	13.10	10.01	10.96	19.6	0.58	12.6	15.9	24.8	114.0
17-5	6.28	6.99	6.25	0.60	0.52	0.53	6.30	5.14	5.94	13.10	10.01	10.96	19.6	0.58	12.6	15.9	24.8	114.0
18-1	7.00	6.94	7.80	0.66	0.98	0.60	8.79	7.13	9.08	11.30	21.27	9.51	33.4	0.25	8.0	8.0	18.2	72.9
19-1	7.68	7.41	7.25	0.75	1.19	1.00	2.79	4.28	3.68	8.50	11.26	16.40	10.0	0.88	8.0	13.5	7.4	106.0
20-1	7.42	7.50	7.40	0.75	0.96	0.69	4.59	0.67	2.11	4.30	17.43	15.26	33.5	0.50	8.0	15.0	13.9	109.0
21-1	7.00	7.83	7.21	0.55	0.49	0.52	3.66	2.87	3.22	6.68	7.18	12.74	49.2	0.28	13.8	8.0	29.8	98.1
21-2	6.88	7.38	6.97	0.62	0.85	0.66	4.69	7.23	5.03	7.13	22.77	19.90	49.2	0.28	13.8	8.0	29.8	98.1
22-1	7.57	7.92	7.13	0.73	0.47	0.36	4.14	5.07	4.52	4.90	11.13	8.19	10.0	0.23	8.0	8.0	3.5	60.7
22-2	7.50	7.50	7.15	0.61	0.86	0.60	1.90	3.15	3.01	5.10	15.86	7.68	10.0	0.23	8.0	8.0	3.5	60.7
23-1	7.63	7.44	7.32	0.67	0.60	0.92	4.60	4.67	5.16	6.67	5.66	14.96	71.9	0.12	8.0	8.0	16.5	74.9
23-2	7.45	7.35	7.93	0.54	0.66	0.52	3.82	2.88	1.60	5.99	4.60	11.12	71.9	0.12	8.0	8.0	16.5	74.9
24-1	4.50	4.12	4.60	0.51	0.63	0.46	4.23	4.63	5.22	5.32	3.33	9.54	75.2	0.15	8.0	8.0	56.2	50.0
24-2	6.30	6.70	6.33	0.35	0.31	0.43	2.87	1.30	3.64	6.49	1.69	16.00	75.2	0.15	8.0	8.0	56.2	50.0

References

1. Gałecka-Drozda, A.; Raszeja, E. Useful wasteland—The potential of undeveloped land in modification of urban green infrastructure based on the city of Poznań. *Misc. Geogr.* **2018**, *22*, 225–230. [CrossRef]
2. Yigitcanlar, T.; Kamruzzaman, M.D. Planning, development and management of sustainable cities: A Commentary from the Guest Editors. *Sustainability* **2015**, *7*, 14677–14688. [CrossRef]
3. Tang, H.-T.; Lee, Y.-M. The Making of sustainable urban development: A synthesis framework. *Sustainability* **2016**, *8*, 492. [CrossRef]
4. Sikorska, D.; Łaszkiewicz, E.; Krauze, K.; Sikorski, P. The role of unmanaged informal green spaces in reducing inequalities in urban green spaces availability to children and seniors. *Environ. Sci. Policy* **2020**, *108*, 144–154. [CrossRef]
5. Nejman, R.; Łepkowski, M.; Wilczyńska, A.; Gawryszewska, B.J. The right to wild. Green urban wasteland in the context of urban planning. *Urban. Dev. Issues* **2018**, *59*, 43–53. [CrossRef]
6. Kelcey, J.G. Industrial development and wildlife conservation. *Environ. Conserv.* **1975**, *2*, 99–108. [CrossRef]
7. Gemmell, R.P.; Connell, R.K. Conservation and creation of wildlife habitats on industrial land in Greater Manchester. *Landsc. Plan.* **1984**, *11*, 175–186. [CrossRef]
8. Small, E.C.; Sadler, J.P.; Telfer, M.G. Carabid beetle assemblages on urban derelict sites in Birmingham, UK. *J. Insect Conserv.* **2003**, *6*, 233–246. [CrossRef]
9. Kowarik, I. Urban wilderness: Supply, demand, and access. *Urban. For. Urban. Green.* **2018**, *29*, 336–347. [CrossRef]
10. Bretzel, F.; Vannucchi, F.; Romano, D.; Malorgio, F.; Benvenuti, S.; Pezzarossa, B. Wildflowers: From conserving biodiversity to urban greening—A review. *Urban. For. Urban. Green.* **2016**, *20*, 428–436. [CrossRef]
11. Hurka, K. *Carabidae of Czech and Slovak Republics*; Kabourek: Zlin, Czech Republic, 1996; p. 565.
12. Koivula, M.J. Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions. *ZooKeys* **2011**, *100*, 287–317. [CrossRef] [PubMed]
13. Kędzior, R.; Skalski, T.; Szwalec, A.; Mundała, P. Diversity of carabid beetle assemblages (Coleoptera: Carabidae) in a post-industrial slag deposition area. *Baltic J. Coleopterol.* **2014**, *14*, 219–227.
14. Ghannem, S.; Touaylia, S.; Boumaiza, M. Beetles (Insecta: Coleoptera) as bioindicators of the assessment of environmental pollution. *Hum. Ecol. Risk Assess.* **2018**, *24*, 456–464. [CrossRef]
15. Avgın, S.S.; Luff, M.L. Ground beetles (Coleoptera: Carabidae) as bioindicators of human impact. *Munis Entomol. Zool.* **2010**, *5*, 209–215.
16. Skalski, T.; Stone, D.; Kramarz, P.; Laskowski, R. Ground beetle community responses to heavy metal contamination. *Baltic J. Coleopterol.* **2010**, *10*, 1–12.
17. Skalski, T.; Kędzior, R.; Kolbe, D.; Knutelski, S. Biegaczowate jako wskaźniki zanieczyszczenia lasów metalami ciężkimi. *Sylwan* **2015**, *159*, 905–911.
18. Laskowski, R.; Bednarska, A.J.; Kramarz, P.E.; Loureiro, S.; Scheil, V.; Kudłek, J.; Holmstrup, M. Interactions between toxic chemicals and natural environmental factors—A meta-analysis and case studies. *Sci. Total Environ.* **2010**, *408*, 3763–3774. [CrossRef]
19. Bayley, M.; Baatrup, E.; Heimbach, U.; Bjerregaard, P. Elevated copper levels during larval development cause altered locomotor behaviour in the adult carabid beetle *Pterostichus cupreus* L. (Coleoptera: Carabidae). *Ecotoxicol. Environ. Saf.* **1995**, *32*, 166–170. [CrossRef]
20. Naccarato, A.; Tassone, A.; Cavaliere, F.; Elliani, R.; Pirrone, N.; Sprovieri, F.; Tagarelli, A.; Giglio, A. Agrochemical treatments as a source of heavy metals and rare earth elements in agricultural soils and bioaccumulation in ground beetles. *Sci. Total Environ.* **2020**, *749*, 141438. [CrossRef]
21. World Population Review. Available online: https://worldpopulationreview.com/world-cities/warsaw-population/ (accessed on 25 April 2020).
22. Koivula, M.; Kukkonen, J.; Niemelä, J. Boreal carabid-beetle (Coleoptera, Carabidae) assemblages along the clear-cut originated succession gradient. *Biodivers. Conserv.* **2002**, *11*, 1269–1288. [CrossRef]
23. Skłodowski, J.J.W. Anthropogenic transformation of ground beetle assemblages (Coleoptera: Carabidae) in Białowieża Forest, Poland: From primeval forests to managed woodlands of various ages. *Entomol. Fennica* **2006**, *17*, 296–314. [CrossRef]
24. Schwerk, A.; Szyszko, J. Model of succession in degraded areas based on carabid beetles (Coleoptera, Carabidae). *ZooKeys* **2011**, *100*, 319–332. [CrossRef] [PubMed]

25. Barber, H.S. Traps for cave inhabiting insects. *J. Mitchel. Soc.* **1931**, *46*, 259–266.
26. Freude, H.; Harde, K.-W.; Lohse, G.A.; Klausnitzer, B. *Die Käfer Mitteleuropas. Bd. 2, Adephaga 1, Carabidae (Laufkäfer). 2. (erweiterte) Aufl.*; Spektrum: Heidelberg/Berlin, Germany, 2004; p. 521.
27. Larsson, S.G. Entwicklungstypen und Entwicklungszeiten der dänischen Carabiden. *Entomol. Meddr.* **1939**, *20*, 277–562.
28. Lindroth, C.H. *Die Fennoscandischen Carabidae: I Spezieller Teil*; Elanders Boktryckeri Aktiebolag: Göteborg, Sweden, 1945; p. 709.
29. Burakowski, B.; Mroczkowski, M.; Stefańska, J. *Katalog fauny Polski (Catalogus faunae Poloniae). Część XXIII, tom 2. Chrząszcze (Coleoptera). Biegaczowate (Carabidae), część 1*; Państwowe Wydawnictwo Naukowe: Warszawa, Poland, 1973; p. 232.
30. Burakowski, B.; Mroczkowski, M.; Stefańska, J. *Katalog fauny Polski (Catalogus faunae Poloniae). Część XXIII, tom 3. Chrząszcze (Coleoptera). Biegaczowate (Carabidae), część 2*; Państwowe Wydawnictwo Naukowe: Warszawa, Poland, 1974; p. 430.
31. Lindroth, C.H. *The Carabidae (Coleoptera) of Fennoscandia and Denmark. Fauna Entomologica Scandinavica. Volume 15, Part II*; Scandinavian Science Press, Ltd.: Leiden, The Netherlands, 1986; p. 497.
32. Dz. U. z 2016 r. poz. 1395. Rozporządzenie Ministra Środowiska z dnia 1 września 2016 w sprawie sposobu prowadzenia oceny zanieczyszczenia powierzchni ziemi. 2016; 86p. Available online: http://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20160001395/O/D20161395.pdf (accessed on 30 September 2020).
33. Ter Braak, C.J.F. *CANOCO—A FORTRAN Program for Canonical Community Ordination by [Partial][Detrended][Canonical] Correspondence Analysis, Principal Components Analysis and Redundancy Analysis (Version 2.1)*; DLO Agricultural Mathematics Group: Wageningen, The Netherland, 1987; p. 95.
34. Ter Braak, C.J.F.; Šmilauer, P. *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5)*; Microcomputer Power: Ithaca, NY, USA, 2002; p. 499.
35. Lepš, J.; Šmilauer, P. *Multivariate Analysis of Ecological Data Using CANOCO*; Cambridge University Press: Cambridge, UK, 2003; p. 269.
36. Przybysz, A.; Wińska-Krysiak, M.; Małecka-Przybysz, M.; Stankiewicz-Kosyl, M.; Skwara, M.; Kłos, A.; Kowalczyk, S.; Jarocka, K.; Sikorski, P. Urban wastelands: On the frontline between air pollution sources and residential areas. *Sci. Total Environ.* **2020**, *721*, 137695. [CrossRef] [PubMed]
37. Van Heerdt, P.F.; Blokhuis, B.; Van Haaften, C. The reproductive cycle and age composition of a population of *Pterostichus oblongopunctatus* (Fabricius) in The Netherlands (Coleoptera: Carabidae). *Tijdschr. Entomol.* **1976**, *119*, 1–15.
38. Bauer, T. Prey capture and structure of the visual space of an insect that hunts by sight on the litter layer (*Notiophilus biguttatus* F., Carabidae, Coleoptera). *Behav. Ecol. Sociobiol.* **1981**, *8*, 91–97. [CrossRef]
39. Skłodowski, J. Manual soil preparation and piles of branches can support ground beetles (Coleoptera, carabidae) better than four different mechanical soil treatments in a clear-cut area of a closed-canopy pine forest in northern Poland. *Scand. J. For. Res.* **2017**, *32*, 123–133. [CrossRef]
40. Ermakov, A.I. Structural changes in the carabid fauna of forest ecosystems under a toxic impact. *Russ. J. Ecol.* **2004**, *35*, 403–408. [CrossRef]
41. Gongalsky, K.B.; Chudnyavtseva, I.I.; Pokarzhevskii, A.D.; Samonov, A.E.; Slobodyan, V.Y. Arsenic bioaccumulation by beetles in an arsenic-rich region. Bull. Environ. *Contam. Toxicol.* **2004**, *72*, 1115–1121. [CrossRef]
42. Belskaya, E.A.; Zinoviev, E.V. Structure of the complexes of carabid beetles (Coleoptera, Carabidae) in natural and industry-disturbed forest ecosystems in the south-west of the Sverdlovsk region. *Siberian J. Ecol.* **2007**, *4*, 533–543.
43. Ashraf, M.A.; Maah, M.J.; Yusoff, I. Chemical speciation and potential mobility of heavy metals in the soil of former tin mining catchment. *Sci. World J.* **2012**, 125608–125611. [CrossRef] [PubMed]
44. Rengel, Z. Availability of Mn, Zn and Fe in the rhizosphere. *J. Soil Sci. Plant. Nut.* **2015**, *15*, 397–409. [CrossRef]
45. Hejna, M.; Gottardo, D.; Baldi, A.; Dell'Orto, V.; Chieli, F.; Zaninelli, M.; Rossi, L. Review: Nutritional ecology of heavy metals. *Animal* **2018**, *8*, 1–15. [CrossRef] [PubMed]
46. Bednarska, A.J.; Laskowski, R.; Pyza, E.; Semik, D.; Świątek, Z.; Woźnicka, O. Metal toxicokinetics and metal-driven damage to the gut of the ground beetle Pterostichus oblongopunctatus. *Environ. Sci. Pollut. Res.* **2016**, *23*, 22047–22058. [CrossRef] [PubMed]

47. Talarico, F.; Brandmayr, P.; Giulianini, P.G.; Ietto, F.; Naccarato, A.; Perrotta, E.; Tagarelli, A.; Giglio, A. Effects of metal pollution on survival and physiological responses in Carabus (Chaetocarabus) lefebvrei (Coleoptera, Carabidae). *Eur. J. Soil Biol.* **2014**, *61*, 80–89. [CrossRef]
48. Sowa, G.; Skalski, T. Effects of chronic metal exposure on the morphology of beetles species representing different ecological niches. *Bull. Environ. Contam. Toxicol.* **2019**, *102*, 191–197. [CrossRef]
49. Šerić Jelaska, L.; Blanuša, M.; Durbešić, P.; Jelaska, S.D. Heavy metal concentrations in ground beetles, leaf litter, and soil of a forest ecosystem. *Ecotoxicol. Environ. Saf.* **2007**, *66*, 74–81. [CrossRef]
50. Tőzsér, D.; Magura, T.; Simon, E.; Mizser, S.; Papp, D.; Tóthmérész, B. Pollution intensity-dependent metal accumulation in ground beetles: A meta-analysis. *Environ. Sci. Pollut. Res.* **2019**, *26*, 32092–32102. [CrossRef]
51. Niemelä, J.; Kotze, D.J.; Venn, S.; Penev, L.; Stoyanov, I.; Spence, J.; Hartley, D.; Montes de Oca, E. Carabid beetle assemblages (Coleoptera, Carabidae) across urban-rural gradients: An international comparison. *Landsc. Ecol.* **2002**, *17*, 387–401. [CrossRef]
52. Bednarska, A.J.; Laskowski, R. Environmental conditions enhance toxicant effects in larvae of the ground beetle *Pterostichus oblongopunctatus* (Coleoptera: Carabidae). *Environ. Pollut.* **2009**, *157*, 1597–1602. [CrossRef] [PubMed]
53. Bednarska, A.J.; Portka, I.; Kramarz, P.E.; Laskowski, R. Combined effect of environmental pollutants (Nickel, Chlorpyrifos) and temperature on the ground beetle, Pterostichus oblongopunctatus (Coleoptera: Carabidae). *Environ. Toxicol. Chem.* **2009**, *28*, 864–872. [CrossRef] [PubMed]
54. Heydemann, B. Die Biotopstruktur als Raumwiderstand und Raumfülle für die Tierwelt. *Zool. Anz.* **1957**, *20*, 332–347.
55. Greenslade, P.J.M. Pitfall trapping as method for studying populations of Carabidae (Coleoptera). *J. Anim. Ecol.* **1964**, *33*, 301–310. [CrossRef]
56. Szyszko, J.; Gryuntal, S.; Schwerk, A. Differences in locomotory activity between male and female *Carabus hortensis* (Coleoptera: Carabidae) in a pine forest and a beech forest in relation to feeding state. *Environ. Entomol.* **2004**, *33*, 1442–1446. [CrossRef]
57. Bradshaw, A.D. The reconstruction of ecosystems. *J. Appl. Ecol.* **1983**, *20*, 1–17. [CrossRef]
58. Rebele, F.; Dettmar, J. *Industriebrachen. Ökologie und Management*; Verlag Eugen Ulmer: Stuttgart (Hohenheim), Germany, 1996; p. 188.
59. Gandy, M. Marginalia: Aesthetics, Ecology, and Urban Wastelands. *Ann. Assoc. Am. Geogr.* **2013**, *103*, 1301–1316. [CrossRef]
60. Kar, D.; Palit, D. Phytoremediation: An Advance Approach for Stabilization of Coal Mine Wastelands. In *Sustainable Agriculture, Forest and Environmental Management*; Jhariya, M., Banerjee, A., Meena, R., Yadav, D., Eds.; Springer: Singapore, 2019; pp. 573–606.