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The effects of anthropogenic disturbances and hydrological activity of a river on soil Collembola communities in an urbanized zone

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ABSTRACT

Soil Collembola communities inhabiting urban zones are highly modified by anthropogenic disturbances. This effect has not yet been studied along an urban river, where hydrological processes play an important role. The main objective of the present study was to test the hypothesis that the impact of anthropogenic disturbances on the variation in Collembola communities is distinctly different in the riparian area of a river and in nearby area not influenced by processes associated with river activity, i.e. exposed only to urbanization. The study was performed in Warsaw and surroundings (Poland) along the Vistula River. Sampling was conducted in three locations, varying with respect to the level of anthropogenic disturbances – in the city center (high level of anthropogenic disturbances), at the edge of city (moderate level of anthropogenic disturbances) and outside of the city (low level of anthropogenic disturbances), each in the area located in front of the levee (prevalent influence of hydrological processes) and behind the levee (lack of river influence), in spring and autumn. The level of anthropogenic disturbances was associated with a significant variation in the Collembola communities only in the area located behind the levee. Season was associated with significant community variation only in the area located in front of the levee, which can be induced by variable hydrological processes. It can be concluded that anthropogenic disturbances do not affect Collembola communities in the riparian area of an urban river, which reflects the high resistance of communities associated with inundated soils to disturbances in a city.

The impact of disturbances on biodiversity is one of the main topics of ecological research (review in Ref. [33]). In urbanized zones, such anthropogenic disturbances as habitat loss, habitat fragmentation, changes in climate and modifications of biogeochemical cycles are prevalent [13]. They significantly affect soil biotopes [18]; therefore, the concept of urban soils emphasizes the role of intensive, non-agrarian human activities in their formation and their unique properties in comparison to nonurban ones [5]. In this way, specific human-associated environmental conditions prevalent in cities distinctly shape the communities of soil fauna, including Collembola [24]. Until now, modifications of Collembola communities under different intensities of anthropogenic disturbances in highly urbanized zones have never been studied in habitats associated with large rivers. Rivers situated in cities are highly polluted and modified with respect to e.g. water level [2]. Their riparian areas are often considerably disturbed as a consequence of conversion to other types of land use, increased erosion of the river channel, increased rate of sediment deposition and changes in hydrology [17]. It is well documented that communities of soil Collembola inhabiting riparian areas are shaped to a large extent by hydrological processes associated with the river [22,28], such as seasonal floods ('flood pulse concept', [12]) and the movement of the ground-water level ('flow pulse concept', [31]). Therefore, the main objective of the present study was to test the hypothesis that the impact of anthropogenic disturbances present in a city on the variation in soil Collembola communities is distinctly different in the riparian area of a river where hydrological processes are prominent and in nearby area not influenced by such processes (i.e. exposed mainly to urbanization).

The study was performed in central Poland, along the Vistula River located in Warsaw and its surroundings. Warsaw is a typical central European city with an area of about 512 km^2 and a population of 2.5 million inhabitants. The Vistula River is the longest river draining to the Baltic Sea. The annual rainfall in the river basin is about 600 mm per year, with a summer maximum. Floods in the Vistula are generated by intense rains, snowmelt and ice-related phenomena. They are seasonally variable. During the growing

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season, they often occur from late June to the end of July due to intense rainfall, but they are very rare in the second half of April and in all of May [4].

The Vistula crosses the middle of the city of Warsaw, from south to north, along a length of approximately 25 km. In the urbanized zone, the river and its valley are highly degraded, especially at the city center. The river channel inside the city is substantially narrowed by protective flood dikes (the so-called 'Warsaw corset'). It was also considerably modified by the extensive dredging of sand and gravel for the post-World War II reconstruction of the city [16]. Outside the city, flood protection is less extensive, so the river and its riparian area are notably less degraded. A large floodplain has not developed, however, at the north of the city, floods can occasionally inundate the entire flood terrace [9].

Collembola sampling was conducted at three locations – in the city center (centered at 52°14′22.68″N, 21°2′23.08″E), where the level of anthropogenic disturbances was high; at the edge of city, approximately 10 km south from the city center (centered at 52°10′22.94″N, 21° 7′39.51″E), where the anthropogenic disturbance level was moderate, and outside the city, in an agricultural zone, approximately 20 km north of the city center, (centered at 52°22′45.78″N, 20°48′56.80″E) where the anthropogenic disturbance level was low.

At each research location, 6 research sites were sampled. Three of them were established in an area situated in front of the levee, directly near the river, in the riparian area. The maximal distance from the river was approximately 200 m, but typically it was much smaller. In this area, Collembola communities were impacted both by anthropogenic disturbances, such as the degradation of riparian habitat in the city center and by hydrological processes frequently associated with the river activity, such as floods [12,] and changes in soil humidity and aeration induced by movements of the groundwater [31]. The other sites were established in an area situated behind the levee, at a typical distance of approximately 500 m from the river. In this area, the above-mentioned river-associated processes were absent, so Collembola communities were shaped mainly by urbanization-related disturbances such as extensive soil degradation by diverse anthropogenic activities (soil alkalization, contamination and enrichment with concrete debris, etc.) that led to formation of urban technosols [14]. The distance between sites along the river was approximately 900 m at each location. Overall 18 sites were sampled. In both areas, research sites were replicated three times at each level of the anthropogenic disturbances. This sampling design allowed representative results for whole of studied region to be obtained. Sampling was performed twice – in late spring (May) and early autumn (September) of 2016, in order to isolate the seasonal variability of Collembola communities associated with e.g. variable hydrological processes. A full list of the research sites with geographical coordinates and sampling dates is provided in Table A1 (Appendix A, on-line supplementary materials).

In the sites situated in the area located in front of the levee, the vegetation has the character of a riparian forest belonging to the *Salicion albae* association. It was highly degraded in the city center, where only a narrow tree belt along the river was preserved. The riparian area itself was mainly devoid of trees and was highly degraded by construction work, especially near bridges. Bare patches of soil and concrete debris were frequently observed. At the edge of the city, riparian forest was better preserved and relatively broad, but it was fragmented into large patches. The riparian area was frequently (but not completely) devoid of trees and was slightly degraded by recreational activities near the hiking trail. It was slightly littered, the vegetation was degraded and soil was compressed locally. Outside the city, the riparian forest was locally narrow, but generally it was in natural condition, with very dense shrubs and a rich herbaceous layer, also in riparian area. The effects of anthropogenic activities were not obvious. In the area located behind the levee the vegetation resembles meadows. In the city center, it was characterized by isolated street lawns similar to the *Arrhenatherion* alliance, which belong to the *Arrhenatheretalia* order. The vegetation in these lawns was generally low and sparse. It was regularly mowed during the maintenance of urban greenery. At the edge of the city, such lawns were generally similar, but they were much larger and less isolated. They were not subject to mowing. Vegetation was high and dense. Outside the city, vegetation has the character of abandoned pastures established after the cessation of agricultural activities approximately 20 years ago and belong to the *Cynosurion* alliance from the *Arrhenatheretalia* order. Human activities were not obvious, therefore, the vegetation was mainly in a natural state. The general appearance of each type of research site is shown in Figure A1 (Appendix A, on-line supplementary materials).

Soils at each location were developed on sandy, Holocene alluvial deposits in both areas. The area located in front of the levee soil belonged to the fluvisols, according to the FAO World Reference Base for Soil Resources [11]. It was similar at each location. In the area located behind the levee, the soil was degraded in the city center and at the edge of the city. In both of these locations, it can be classified as technosols. It was affected by e.g. a high accumulation of various technogenic deposits, such as concrete debris and limestone rubble in the profile. Soil degradation was notably higher in the city center, where the presence of rubble was very obvious. Outside of the city, the soil was very similar to that found in the riparian area.

At each research site, three soil cores with an area of 5 cm in diameter and 10 cm in depth were taken at random during each sampling occasion. Collembola were extracted from soil cores using a modified MacFadyen high gradient extractor for a maximum of 10 days. The obtained specimens were identified to species level and deposited at the Museum and Institute of Zoology, PAS. Collembola communities were characterized by basic ecological indices – total abundance (A), species richness (S), Shannon diversity index (H′) and Pielou evenness index (J′).

To check whether basic community indices could be ordinate to the studied factors, a canonical correspondence analysis (CCA) was applied [30]. The calculated model was constrained by 'season' (spring and autumn), 'river activity' (areas situated in front of and behind the levee) and 'disturbances' (high, moderate and low level of anthropogenic disturbances).

To identify the relationships between environmental factors and variation in the Collembola communities at the level of species composition, a variation decomposition within series of CCA and partial CCA (pCCA) analyses were applied. First, an ordination model constrained by 'season', 'river activity' and 'disturbances' was calculated for the whole dataset. It was intended to isolate the influence of river-associated processes to variation in Collembola communities in the whole studied region. Second, two separate ordination models were calculated, individually for areas situated in front of and behind the levee, constrained by 'disturbances' and 'season'. They allow to examine the impact of the studied factors in the presence and absence of hydrological processes associated with river activity. In each ordination model, the pure effect of a particular factor was assessed when the remaining factors were removed and used as covariates. Treatment of a particular factor alternatively in the analysis as an explanatory variable or covariate allowed the interpretation of the effect of a given factor independently of interactions with other factors [1].

All statistical analyses were performed with a data matrix in which the values of Collembola species abundances in each cell were calculated from the sum of individuals counted in three