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STRUCTURE OF SOIL CLICK BEETLE (*COLEOPTERA, ELATERIDAE*) COMMUNITIES IN URBAN GREEN AREAS OF WARSAW

ABSTRACT

This paper is a continuation of earlier publications on soil click beetles occurring in urban green areas. It analyses changes in the species composition, numbers, dominance structure, and proportion of zoogeographical and ecological elements in response to urban pressure. It has been found that most of the green areas of Warsaw established on the site of former linden-oak-hornbeam forests are inhabited by one community of soil click bettles, dominated by *Agriotes sputator*. Only the old, large Łazienki Park supported a semi-natural community dominated by *Agriotes sputator* and *Cidnopus pilosus*.

INTRODUCTION

This paper is a continuation of earlier works on click beetles of Warsaw. It is based on the study conducted at the Institute of Zoology PAS in 1974—1978. The preceding paper concerned the composition and origin of the elaterid fauna of Warsaw (Burakowski, Nowakowski 1981). Some information on the structure of elaterid communities is also given in two other papers (Kubicka, Nowakowski 1982, Nowakowski 1982).

Soil click beetles are an important part of the soil macrofauna. Their larvae account for 10—30% of this fauna, excluding ants. Larval elaterids are characterized by a long developmental cycle covering from three to six years, depending on microhabitat and food conditions. Adult forms live only two to three weeks. For this reason more ecological importance is attributed to larvae. Heavily sclerotic body, solid head, strong mandibles, grubbing legs, and a specific structure of the last segment of the abdomen allow them active movements in soil. Hence they can aggregate in places with optimum moisture conditions. They can also migrate across the soil profile. This group has diversified food habits, but the diet of some species is not fully known yet. According to the generally accepted classification, they comprise predatory polyphages, pantophages, and rhizophagous polyphages. In this last group also cannibalism and feeding on dead earthworms were observed. Most elaterids have no economic importance, few are beneficial, and many rhizophagous species are crop and forest pests. Adults live in herbaceous and shrubby vegetation. These are phyto- and melitophages feeding on leaves and pollen. They frequently move over different habitats such as forests, meadows and crop fields. Thus, unlike the larvae,

adult forms can be casual components of a zoocoenosis. As they are short-lived and usually scarce, they are of no economic importance.

STUDY AREAS, METHODS, AND MATERIAL

The study of soil click beetles formed a part of comprehensive studies of soil macrofauna in urban habitats. The theoretical basis of zoocoenological studies in urban green areas was given by Trojan (1981). The investigation was carried out in ten study areas, in which 24 plots were selected. These sites represented three types of urban green areas: parks, green areas of housing estates, and streetside green.

The following parks were under study:[1] the palace park at Ursynów (the area of the Agricultural Academy; during the study it was located at the outskirts of Warsaw), the Łazienki Park (3 plots: I — on the upper terrace of the Vistula river, II and III on the lower terrace), the park at the Cemetery of Soviet Soldiers (2 plots: I — at a distance of about 25 m to Żwirki i Wigury Avenue, II — in the centre of the park), the Saxon Garden (plot II — in the centre of the park), the Praski Park (3 plots: I — open lawn at a distance of about 10 m to Świerczewskiego Avenue, II and III — in the central part of the park).

The green of housing estates in loosely built-up areas was examined in the Wierzbno housing estate on 2 plots (I — a large open lawn spotted with single several-year-old lindens, surrounded with tall buildings, and II — a smaller lawn with dense cover of saplings more than 10 years old, surrounded by 5-storied buildings. In this paper also author's own data collected in the Rakowiec housing estate for several years are used. Sampling plots were located in loosely built-up areas with tall buildings and large lawns with scarce several-year-old saplings; some of these lawns were not managed, and they supported a ruderal vegetation of the *Tanaceto-Artemisietum* community on a very fine sandy soil of alluvial accumulation. The green of closely built-up areas of central parts of the town was examined at Wilcza Street, M.D.M. (plot I) and Hoża Street.

The streetside green was examined at Ujazdowskie Avenue, Żwirki i Wigury Avenue (2 plots: I — a lawn bordering on the park at the Cemetery of Soviet Soldiers, and II — an interlane lawn), Marszałkowska Street (an interlane lawn at the height of the Saxon Garden), Woronicza Street (2 plots: I — streetside lawn, and II — a wide lawn bordering on buildings separated from plot I by a 2 m sidewalk),[2] Niepodległości Avenue (an

[1] The symbols of plots (I, II, etc.,) according to Kubicka et al. (1986).

[2] In the introductory paper (Kubicka et al. 1986) these two lawns are treated as one plot.

Table 1. Occurrence of soil click beetles in the parks of Warsaw
(n — number of individuals per m^2; + — data obtained by other methods)

No.	Study area, plot / Species	Ursynów		Łazienki Park						Cemetery of Soviet Soldiers				Saxon Garden		Praski Park					
				I		II		III		I		II		II		I		II		III	
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
1	*Adelocera murina* (L.)	1.7	3.8	–	–	+	–	+	–	5.8	8.5	2.5	6.5	1.0	3.4	2.5	2.7	–	–	1.3	2.3
2	*Selatosomus latus* (F.)	–	–	–	–	–	–	–	–	2.5	3.7	2.5	6.5	–	–	–	–	–	–	–	–
3	*Prosternon tessellatum* (L.) [1]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4	*Cidnopus pilosus* (Leske)	–	–	8.5	24.6	40.0	67.2	2.5	21.7	–	–	–	–	–	–	–	–	–	–	–	–
5	*Cidnopus aeruginosus* (Oliv.)	–	–	–	–	–	–	–	–	–	–	0.8	2.1	–	–	–	–	–	–	–	–
6	*Athous hirtus* (Herbst)	–	–	+	–	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–
7	*Athous niger* (L.)	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
8	*Athous haemorrhoidalis* (F.)	–	–	+	–	–	–	1.0	8.7	+	–	1.7	4.4	–	–	–	–	–	–	–	–
9	*Agriotes sputator* (L.)	38.3	85.1	24.0	69.6	19.5	32.8	5.0	43.5	55.0	80.5	28.3	73.9	28.0	96.6	88.8	95.9	17.5	66.7	53.7	97.7
10	*Agriotes obscurus* (L.)	5.0	11.1	2.0	5.8	–	–	0.5	4.3	5.0	7.3	2.5	6.5	–	–	1.3	1.4	8.8	33.3	–	–
11	*Adrastus rachifer* (Fourcr.)	+	–	+	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–
12	*Adrastus limbatus* (F.)	–	–	–	–	–	–	1.0	8.7	–	–	–	–	–	–	–	–	–	–	–	–
13	*Adrastus pallens* (F.)	–	–	+	–	+	–	1.5	13.0	–	–	–	–	–	–	–	–	–	–	–	–
14	*Dalopius marginatus* (L.) [2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
15	*Dicronychus cinereus* (Herbst)	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Total	45.0		34.5		59.5		11.5		68.3		38.3		29.0		92.6		26.3		55.0	
	Number of species	4		7		6		8		6		7		3		3		2		2	

[1] Culture and Leisure Park [according to Nowakowski (1979)
[2] Łazienki Park (quotation as above)

interlane lawn divided by a tramway line), and Zbawiciela Square (a completely isolated interlane lawn). The location and general description of the study areas are given by Nowakowski (1981a), and a detailed presentation of them can be found in the paper by Kubicka et al. (1986).

For comparative purpose, also two semi-natural sites in Białołęka Dworska were under study. One was a moist meadow (*Arrhenatheretum medioeuropeum*) on a brown soil, moderately moist, made of loam (Nowakowski 1981b); the other was a fallow supporting a community of the class *Artemisietea* on brown soil, made of loam.

The methods used for soil macrofauna sampling were adapted to a specific character of the work in urban habitats (Nowakowski 1978, Czechowski, Mikołajczyk 1981). A total of 1400 click beetles, mostly larvae, were collected. The material was supplemented with adult forms captured by other methods.

STRUCTURE OF THE COMMUNITIES

SPECIES COMPOSITION

In urban green areas of Warsaw, 16 species of soil click beetles were recorded. Parks were inhabited by 15 species, green areas of housing estates by 11 species, and streetside green by 9 species.

The richest fauna of soil elaterids was found in large urban parks such as the Łazienki Park — 12 species, and the park at the Cemetery of Soviet Soldiers — 8 species. In each of the two other urban parks, the Praski Park and the Saxon Garden, 3 species were recorded, and in the peripheral palace park in Ursynów, 4 species (Tab. 1).

In the group of study areas representing green areas of housing estates the following number of species was recorded: 8 species in loosely built-up areas of Wierzbno (one species, *Dalopius marginatus*, probably introduced), 5 species in Rakowiec, 5 species in closely built-up areas of Wilcza Street, 3 species in M.D.M. I (at least one, *Adrastus pallens*, introduced), and zero species at Hoża Street (Tab. 2).

In the group of streetside study areas, 3 species were recorded at Ujazdowskie Avenue, 7 species at Żwirki i Wigury Avenue, 2 species at Marszałkowska Street, 4 species at Woronicza Street, 2 species at Niepodległości Avenue, and 1 species at Zbawiciela Square (Tab. 3).

The above figures show that the number of species drastically declines with increasing urban pressure. The number of species also declined from park centres towards streetside green. This was caused by the elimination of the species that survived only in large parks and could not resist a heavy urban pressure. In the Łazienki Park, two polytopic species associated

Table 2. Occurrence of soil click beetles in the greenery of housing estates (symbols as in Tab. 1)

No.	Study area, plot / Species	Wierzbno I		Wierzbno II		Rakowiec	Wilcza Street		MDM I		Hoża Street	
		n	%	n	%		n	%	n	%	n	%
1	*Adelocera murina* (L.)	–	–	0.5	1.2	–	0.5	4.9	–	–	–	–
2	*Selatosomus latus* (F.)	–	–	1.3	3.0	+	–	–	–	–	–	–
3	*Athous hirtus* (Herbst)	–	–	–	–	–	+	–	–	–	–	–
4	*Athous niger* (L.)	–	–	–	–	+	–	–	–	–	–	–
5	*Athous haemorrhoidalis* (F.)	–	–	+	–	–	–	–	–	–	–	–
6	*Agriotes sputator* (L.)	86.8	82.8	37.3	88.1	+	8.8	85.4	3.8	75.0	–	–
7	*Agriotes obscurus* (L.)	13.5	12.9	2.8	6.5	–	1.0	9.7	–	–	–	–
8	*Agriotes lineatus* (L.)	4.5	4.3	0.5	1.2	+	+	–	–	–	–	–
9	*Adrastus rachifer* (Fourcr.)	+	–	–	–	+	–	–	0.6	12.5	–	–
10	*Adrastus pallens* (F.)	–	–	–	–	–	–	–	0.6	12.5	–	–
11	*Dalopius marginatus* (L.)	+	–	–	–	–	–	–	–	–	–	–
	Total	104.8		42.4		no data	10.3		5.0		–	
	Number of species	5		6		5	5		3		zero	

Table 3. Occurrence of soil click beetles in streetside and interlane lawns
(symbols as in Tab. 1)

No.	Study area, plot / Species	Ujazdowskie Avenue		Żwirki i Wigury Avenue I		Żwirki i Wigury Avenue II		Marszałkowska Street		Woronicza Street I		Woronicza Street II		Niepodległości Avenue		Zbawiciela Square	
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
1	*Adelocera murina* (L.)	–	–	+	–	1.3	4.7	0.5	0.6	–	–	3.8	2.9	–	–	–	–
2	*Selatosomus latus* (F.)	–	–	⩽0.5	⩽1.2	–	–	–	–	–	–	3.8	2.9	–	–	–	–
3	*Cidnopus pilosus* (Leske)	1.4	14.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4	*Athous hirtus* (Herbst)	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
5	*Athous haemorrhoidalis* (F.)	–	–	2.4	5.8	–	–	–	–	–	–	–	–	–	–	–	–
6	*Agriotes sputator* (L.)	8.3	85.6	38.8	94.2	26.2	95.3	79.4	99.4	33.0	98.5	122.5	94.2	33.2	93.3	131.3	100.0
7	*Agriotes obscurus* (L.)	–	–	–	–	–	–	–	–	0.5	1.5	–	–	2.4	6.7	–	–
8	*Adrastus rachifer* (Fourcr.)	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–
9	*Dalopius marginatus* (L.)	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–
	Total	9.7		41.2		27.5		79.9		33.5		130.1		35.6		131.3	
	Number of species	3		6		3		2		2		3		2		1	

with forests were recorded. These were *Dicronychus cinereus* and *Dalopius marginatus*. The occurrence of the latter was limited to the Vistula escarpment in the park; it did not move to adjacent lawns (Nowakowski 1979). The third polytopic species characteristic of forests was found on the escarpment in the Culture and Leisure Park, located close to the Łazienki Park (Nowakowski 1979). The Łazienki Park was also the only place of the occurrence of stenotopic species associated with open habitats, such as *Cidnopus pilosus*, *Adrastus limbatus*, and *Adrastus pallens* (a larva of this species found in MDM was probably accidentally introduced there; this will be discussed further in this paper). The park at the Cemetery of Soviet Soldiers was the only site of *Cidnopus aeruginosus*, a scarce eurytopic species occurring in open tree stands and old fields, less frequently in crop fields.

An absolutely constant species in urbicoenosis (according to the 4-degree Tischler's scale) was only *Agriotes sputator*, an oligotopic species living in open habitats (C=96%). It has not been recorded from only one plot at Hoża Street, where soil click beetles did not occur at all. The group of constant species (50% < C ⩽ 75%) was also represented by only one species — predatory, eurytopic *Adelocera murina* (C=58%). The group of accessory species (25% < C ⩽ 50%) consisted of two rhizophagous species, *Agriotes obscurus* (C=50%) and *Adrastus rachifer* (C=37.5%). Since the latter species, which occurs on the left side of the Vistula, is not known from other sites of Mazovia, it is suggested that the population inhabiting the urbicoenosis was originated by specimens carried by the Vistula from southern parts of the country (Burakowski, Nowakowski 1981). Recently another natural site of this species in the Mazovian Lowland was discovered at the village of Klembów, near Wołomin (Burakowski, Mroczkowski, Stefańska 1985); this does not put in question, however, the thesis on the alien character of the Warsaw population.

The group of accidental species, occurring on at most 6 plots (C ⩽ 25%), was made up of the remaining 12 species. Among them the most constant were *Athous haemorrhoidalis* and *Selatosomus latus* (C=25%), also *Athous hirtus* (C=20.8%). *S. latus* has an interesting distribution in urban habitats. It has been found on only 6 plots (Tabs 1—3) representing different types of urban green, but located close to each other (Nowakowski 1981). A common feature of these plots is soil type — a very fine sandy soil or sandy loam near very fine sandy soil (Kubicka et al. 1985). These are alluvial sediments, thus physiographically distinct from the underlying rocks of the remaining part of the left-side of Warsaw. This is, however, the same site type of the fertile variety of linden-oak-hornbeam forest (*Tilio-Carpinetum*). A similar range was also characteristic of species of other taxonomic groups, such as *Cicindela germanica* L. of the family *Carabidae* (Czechowski 1982).

The group of accidental species also included elements introduced with peat used for fertilizing lawns, or with earth supplied. Also some visitors were recorded. One of the introduced species was *Dalopius marginatus*. It was caught in Barber's pitfall traps in Wierzbno (I) and at Żwirki i Wigury Avenue (II), one specimen at each of these plots (Tabs 2 and 3). These could not be visiting specimens because of a large distance to forested areas. Another example of introduction is an insular occurrence in the centre of the town (M.D.M. I) of a hygrophilous species, *Adrastus pallens*. The larvae of the genus *Adrastus* Eschsch. found there represented two different species. One was identified as *A. rachifer*, and this was confirmed by the capture of an adult form, the other was identified as *A. pallens*.

A visiting element, at least in the centre of the town, is a large click beetle, *Athous hirtus*, an adult form of which was captured at Wilcza Street and on other sites where Barber's traps were used but soil macrofauna was not examined. A casual introduction of larval beetles with earth or peat probably accounted for the occurrence of a large number of species in the town, but this cannot be proved unless these species have disjunct ranges, insular occurrence, or are highly specialized in their requirements.

A partly artificial origin of the elaterid fauna on at least some plots in closely built-up urban areas can be inferred from a comparison of the species composition of elaterid communities on these plots by means of the Sørensen's formula (Fig. 1). Similarity of the species composition on the Wilcza Street and M.D.M. I plots, which are closely located was very low, merely 25%. Moreover, owing to the presence of the two species of the genus *Adrastus* Eschsch., which were mentioned above, the elaterid community of the M.D.M. I plot showed a closer similarity only to those of the Łazienki Park and nearby streetside site at Ujazdowskie Avenue, while it was significantly different from the communities living on other urban plots and in the compared transformed habitats in Białołęka Dworska, including a moist meadow and a fallow (Fig. 1). The species composition of click beetles on the Wilcza Street plot was similar to that on most plots, but not very similar to that in the Łazienki Park.

Of the total number of 24 plots in urban green areas, only 8 supported click beetle communities showing more than 50% similarity to the community on the moist meadow in Białołęka Dworska, and 11 plots were occupied by the communities similar in more than 50% to the community on the fallow. A high similarity to the community living on the moist meadow was noted for large urban parks such as Łazienki (plots I and III) and the park at the Cemetery of Soviet Soldiers (plots I and II), for green areas of housing estates such as Wierzbno II and Rakowiec, also at Wilcza

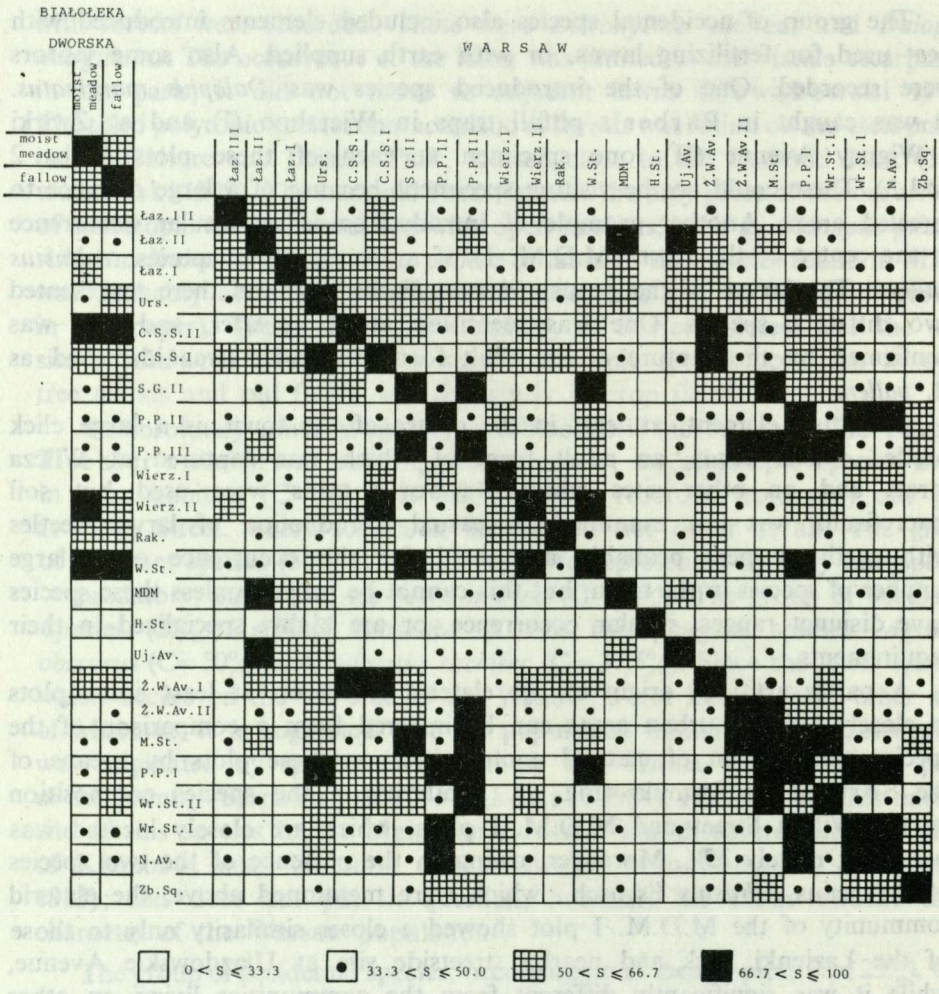


Fig. 1. A diagram of similarity in species composition (S) of click beetle communities in urban green areas of Warsaw and in two suburban habitats of Białołęka Dworska. Symbols of the study areas: Łaz. — Łazienki Park; Urs. — Ursynów; C.S.S. — Cemetery of Soviet Soldiers; S.G. — Saxon Garden; P.P. — Praski Park; Wierzb. — Wierzbno; Rak. —Rakowiec; W.St. — Wilcza Street; H. St. — Hoża Street; Uj.Av. — Ujazdowskie Avenue; Ż. W. Av. — Żwirki i Wigury Avenue; M. St. — Marszałkowska Street; Wr.St. — Woronicza Street; N. Av. — Niepodległości Avenue; Zb.Sq. — Zbawiciela Square

Street and on streetside plot at Żwirki i Wigury Avenue (plot I). A high similarity of more than 50% to the click beetle community occurring in the fallow was noted for all the plots mentioned above, except Łazienki I, and also for Ursynów, Saxon Garden II, Praski Park I, and Woronicza Street II.

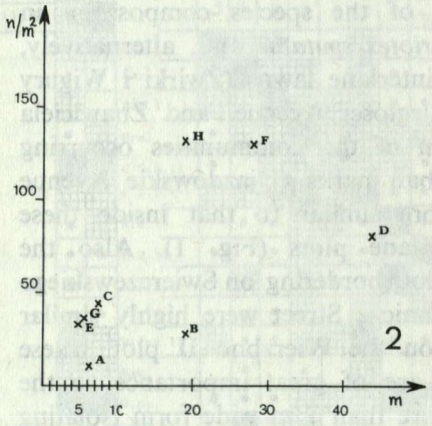
Using the similarity index of the species composition of elaterid communities, as calculated from the Sørensen's formula, it is possible to determine the effect of large green areas on elaterid communities occupying streetside and interlane green areas. It has already been shown that the increasing urban pressure accounts for a simplification of the species composition. This simplification leads to a unification of the species composition in communities made up of 1—2 species (*Agriotes sputator* and, alternatively, *Adelocera murina* or *Agriotes obscurus*) in interlane lawns (Żwirki i Wigury Avenue II, Marszałkowska Street, Niepodległości Avenue, and Zbawiciela Square). However, the species composition of the communities occurring in streetside lawns bordering on large urban parks (Ujazdowskie Avenue and Żwirki i Wigury Avenue I) was more similar to that inside these parks than to other streetside and interlane plots (Fig. 1). Also the communities occupying the Praski Park I plot, bordering on Świerczewskiego Avenue, and the streetside plot II at Woronicza Street were highly similar to the communities living in parks and on the Wierzbno II plot. These facts show that the adjacent green areas are of great importance to the fauna occupying streetside green. Streets more than 7 m wide form isolating barriers that preclude click beetle migration into interlane lawns from neighbouring areas.

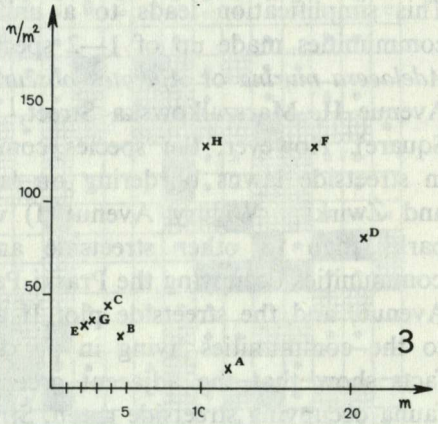
NUMBERS

Also the density of wireworms can be a measure of urbanization and pollution. In parks, changes in density were not large. They ranged between 33 and 55 specimens per sq. m, with an average of 40 specimens per sq. m. Similar values have also been recorded in natural linden-oak-hornbeam forests. It was shown earlier that the density of rhizophagous click beetles in soil increased with declining soil moisture (as a result of better insolation) (Kubicka, Nowakowski 1982). Their highest densities were recorded in large open lawns on the Wierzbno I and Woronicza Street II plots (Tabs 2 and 3). It seems thus that the vertical structure of urban green areas can be of basic importance to reduce the density of soil click beetles, particularly rhizophages that can do some damage.

Very large differences in densities were found on heavily polluted streetside and interlane plots. They ranged from 10 to more than 130 specimens per sq. m (Tab. 3). No correlation was found, however, between the wireworm density and the pollution of surface soil layer with lead (Kubicka, Nowakowski 1982, Nowakowski 1982). This correlation could be obliterated by an opposite effect of the size of the lawns, or intrapopulation regulatory mechanisms due to which a high mortality could be compensated by an increased fecundity.

To find which of the measurable factors (surface area of lawns, their width, or distance from the kerb to the centre of the lawn) can affect the density of click beetles in soil, correlation coefficients were calculated (Figs 2—4). No relationship was found between the density and these





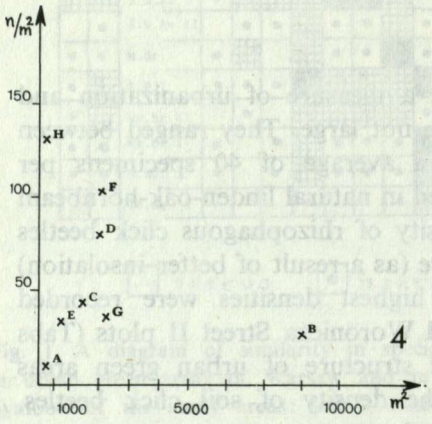


Fig. 2. Density (number of individuals per sq. m) of soil elaterid communities in relation to the width (in metres) of streetside and interlane lawns: A — Ujazdowskie Avenue, B — Żwirki i Wigury Avenue II; C — Żwirki i Wigury I; D — Marszałkowska Street; E — Woronicza Street I; F — Woronicza Street II; G — Niepodległości Avenue, H — Zbawiciela Square

Fig. 3. Density (number of individuals per sq. m) of soil elaterid communities in relation to the distance (in metres) of the lawn centre to the kerb. A — H as in Fig. 2

Fig. 4. Density (number of individuals per sq. m) of soil elaterid communities in relation to the surface area (in square metres) of lawns. A—H as in Fig. 2

factors. The correlation coefficient between the density and lawn width was 0.63, between the density and the distance to the centre of the lawn it was 0.53, and between the density and the surface area of the lawn it was low and negative (−0.25). It follows from this that the wireworm density cannot be directly related to any of these habitat characteristics. It is possible that such relationships exist in some ranges of the value of this factors (particularly in the case of the lawn width), but the number of plots was too low to eliminate the effect of other factors acting in an opposite direction.

A distinct group of plots characterized by a very low wireworm density were lawns located in closely built-up, central parts of the town. These were usually small lawns, located mainly on rubble soils. The density of click beetles there was 0—10 specimens per sq. m, certainly because of a sparse sod and a shallow root system. On these plots, also the density of rhizophages was the lowest, and the only group of rhizophages the density of which reached slightly higher values, as compared with other plots, was *Halticinae* (*Chrysomelidae*) (Kubicka, Nowakowski 1982).

DOMINANCE STRUCTURE

To determine the similarity in dominance structures for soil elaterids on the study plots, the Morisita index was calculated according to the formula:

$$c = \frac{2\Sigma x_i\, y_i}{\Sigma x_a^2 + \Sigma y_a^2}$$

where x_i and y_i are percentage proportions of the species common to two communities, while x_a and y_a are percentage proportions of all species in the community (Horn 1966).

Also the structure of the wireworm communities from transformed habitats in Białołęka Dworska was compared with that from different types of urban green areas. The results are set in a diagram, and different size classes of the similarity index were distinguished on the basis of the frequency of different values (Fig. 5).

In this way, two types of elaterid communities were distinguished. One type inhabited the Łazienki Park. This community clearly differed from the communities living in other types of urban green areas (Fig. 5). It was dominated by *Agriotes sputator* and *Cidnopus pilosus*, and characterized by a considerable variableness, depending on local site conditions. Of all the plots in the Łazienki Park, most distinct from other urban plots were plots II and III, both located on the lower Vistula terrace, while plot I, located on the upper terrace, was least distinct. At the same time, the latter community was most similar (c=0.997) to that inhabiting seminatural

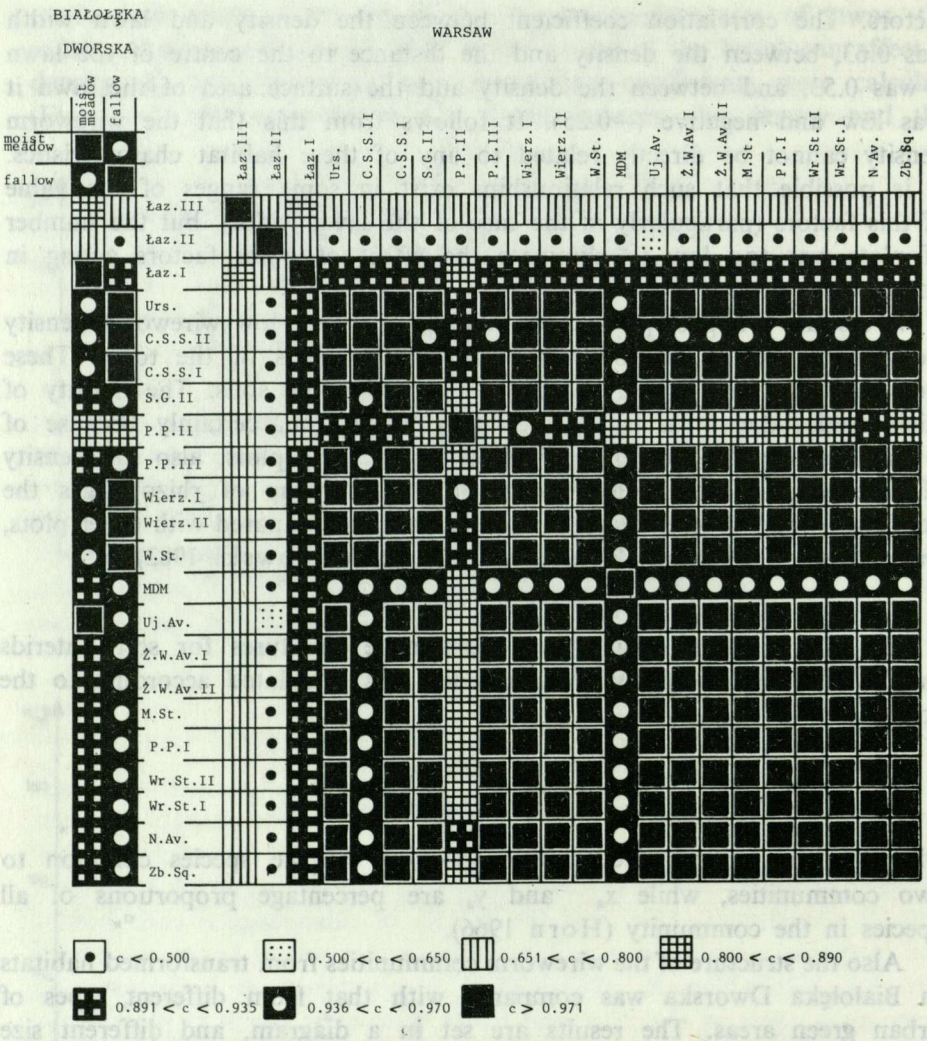


Fig. 5. A diagram of similarity in dominance structure (c) of elaterid communities in urban green areas of Warsaw and in two suburban habitats of Białołęka Dworska. Symbols as in Fig. 1

soils of perennial mown meadows of the *Arrhenatheretum medioeuropeum* association, while much less similar to wireworm communities living in fallows several years old (Figs 5 and 6). The community recorded on the Ujazdowskie Avenue plot can be considered as a heavily impoverished variant of this community. Its dominance structure was already similar ($c > 0.970$) to the structure of wireworm communities in other urban plots.

The distinct character of soil click beetle fauna in the Łazienki Park, combined with a very high similarity in the dominance structure on plot I

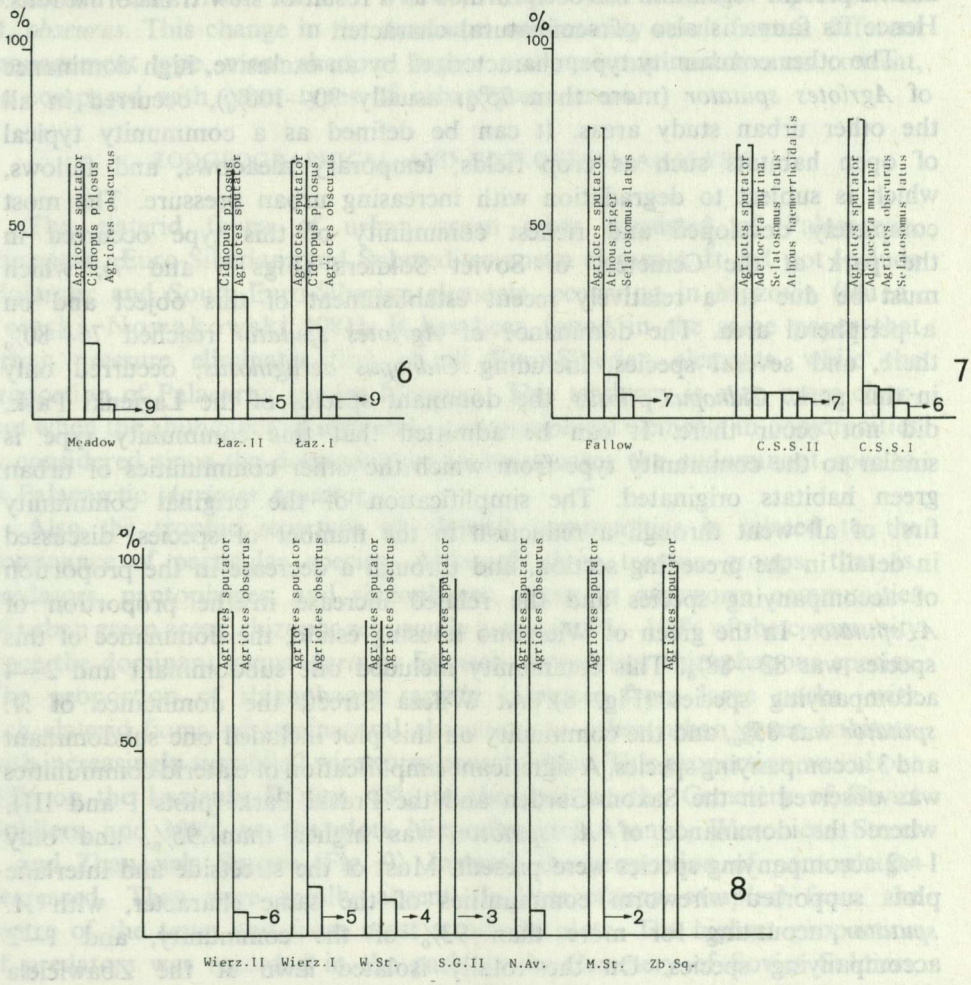


Fig. 6. A comparison of the dominance structure of elaterid communities in a moist meadow of Białołęka Dworska and on two plots of the Łazienki Park (Łaz.) in Warsaw. Numerals denote a total number of species (the same in Figs 7 and 8)

Fig. 7. A comparison of the dominance structure of elaterid communities in a fallow of Białołęka Dworska and on two plots of the Cemetery of Soviet Soldiers (C.S.S.) in Warsaw

Fig. 8. A comparison of the dominance structure of elaterid communities on other plots of urban green areas of Warsaw. Symbols as in Fig. 1

to that in moist meadows is in accordance with the historical development of the town. The Łazienki Park was established on an area covered with a forest, and its present vegetation has been formed as a result of slow transformations. Hence its fauna is also of seminatural character.

The other community type, characterized by an exclusive, high dominance of *Agriotes sputator* (more than 75%, usually 90—100%), occurred in all the other urban study areas. It can be defined as a community typical of open habitats such as crop fields, temporary meadows, and fallows, which is subject to degradation with increasing urban pressure. The most completely developed and richest community of this type occurred in the park at the Cemetery of Soviet Soldiers (Figs 5 and 7), which must be due to a relatively recent establishment of this object and on a peripheral area. The dominance of *Agriotes sputator* reached 75—80% there, and several species, including *Cidnopus aeruginosus,* occurred only in this park. *Cidnopus pilosus,* the dominant species of the Łazienki Park, did not occur there. It can be admitted that this community type is similar to the community type from which the other communities of urban green habitats originated. The simplification of the original community first of all went through a reduction in the number of species, discussed in detail in the preceding section, and through a decrease in the proportion of accompanying species and the related increase in the proportion of *A. sputator*. In the green of Wierzbno housing estate, the dominance of this species was 82—88%. This community included one subdominant and 2—4 accompanying species (Fig. 8). At Wilcza Street, the dominance of *A. sputator* was 85%, and the community on this plot included one subdominant and 3 accompanying species. A significant simplification of elaterid communities was observed in the Saxon Garden and the Praski Park (plots I and III), where the dominance of *A. sputator* was higher than 95%, and only 1—2 accompanying species were present. Most of the streetside and interlane plots supported wireworm communities of the same character, with *A. sputator* acounting for more than 93% of the community, and 1—2 accompanying species. On the totally isolated lawn at the Zbawiciela Square, the dominance of *A. sputator* reached 100% (Fig. 8).

At present it is difficult to say whether the wireworm community on the Praski Park II plot, which is clearly distinct, represented a separate, much simplified variant of the third community type, corresponding to different site conditions (unlike other study areas Praski Park is on the site of a mixeed deciduous-coniferous forest), or this is a local variant of the community described above. There were no indicatory species in it, and the subdominant *Agriotes obscurus* is abundant in both most soils and dry soils with a high content of sand.

Certainly, the elaterid community occuring in allotments, a totally

different type of urban green, represented a variant of the second community type described above, and characteristic of urban green areas. Its composition is known only from Barber's pitfall traps. The dominant species was *A. obscurus*. This change in the dominant species may result from a different management type, more shadow, higher soil moisture and humus content, as compared with other types of urban green areas.

ZOOGEOGRAPHICAL AND ECOLOGICAL ANALYSIS

The elaterid fauna of urban green areas consisted of Palaearctic, European, Euro-Siberian, and Submediterranean elements. It did not include Holarctic and South-Euro-Siberian elements, occurring in Mazovia (Burakowski, Nowakowski 1981). It has been found in the same paper that urban pressure eliminates first of all Euro-Siberian elements, while the proportion of Palaeartic species increases. This tendency is even more clear-cut when the abundance of different zoogeographical elements in communities is considered since the dominant, or in most cases the eudominant species, is Palaearctic *Agriotes sputator*.

Also the trophic structure of elaterid communities is related to the dominance of particular species. Although three trophic groups, that is, predators, pantophages, and rhizophages, occur in wireworm communities of urban green areas, rhizophages usually comprise 95—100% of the community since the dominant genus *Agriotes* Eschsch., comprises rhizophagous species. The proportion of rhizophages rapidly increases from large parks, with rich elaterid fauna of seminatural character, to other urban green habitats, with increasingly simplified wireworm communities. This proportion was about 33% on the Łazienki II plot, 88% in the park at the Cemetery of Soviet Soldiers, and 100% on the plots Niepodległości Avenue, Woronicza Street I, and Zbawiciela Square (Fig. 9). Instead, the proportion of pantophages decreased. They were totally absent (in macrofauna samples) from the centre of the town and from most streetside plots. The highest proportion of predators was recorded in the park at the Cemetery of Soviet Soldiers, where it ranged between 6.5 and 10%. They also occurred in the Łazienki Park (in Barber's traps) but in small numbers (absent from macrofauna samples). In green areas of housing estates and in some streetside green areas (Żwirki i Wigury Avenue I and II, Marszałkowska Street), predators contributed up to 5% of the community (Fig. 9).

TRANSECT ANALYSIS

As already noted, the effect of urban pressure is revealed not only when wireworm communities are analyzed in particular types of urban green areas but also along transects such as inside park or housing

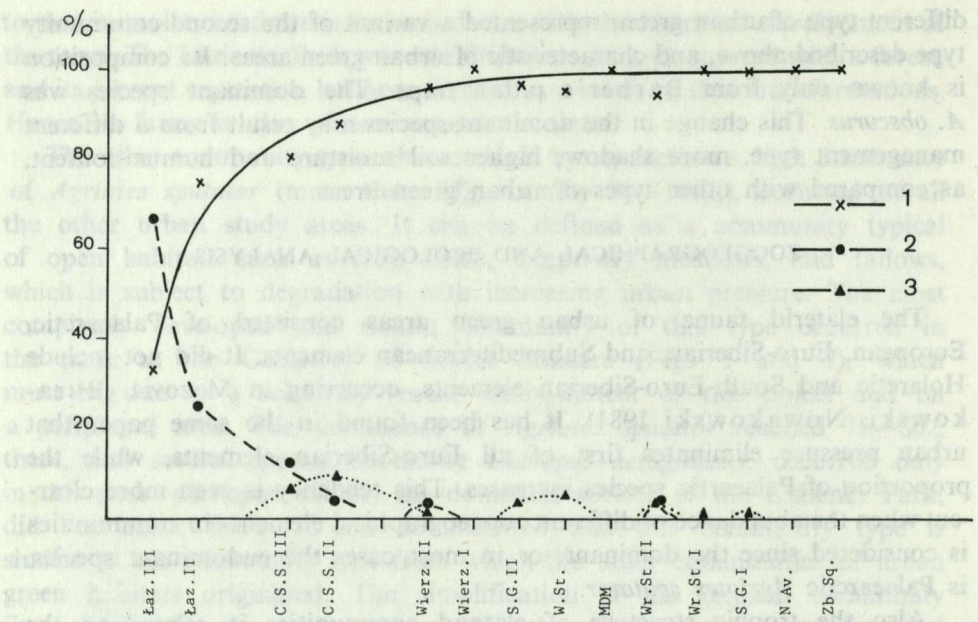


Fig. 9. Changes in the proportion (%) of trophic groups in soil elaterid communities with increasing urban pressure. 1 — rhizophages; 2 — pantophages; 3 — predators; symbols of the plots as in Fig. 1

estate plots — adjacent streetside and interlane plots. A ideal transect would consist of a series of sites with only one factor of urban pressure changing its intensity, edaphic and habitat conditions being identical. In practice, however, it was not possible to establish such a transect — the size of lawns varied, also tree cover, soil insolation, and sometimes soil types were different. Moreover, streetside and interlane plots were heavily overdried as compared with park plots, and their soils were largely degradated as a result of peptization, differences in humification of organic matter, low oxygen content, and the related predominance of anaerobic respiration.

The most representative series of plots along the transects, in which an indirect measure of urban pressure is the distance of the plot to the source of pollution, that is, to the street, comprised the plots in the park at the Cemetery of Soviet Soldiers, and Żwirki i Wigury Avenue, as well as in the Wierzbno housing estate and Woronicza Street. All these sites had identical soil type, and their streetside plots (Żwirki i Wigury I and Woronicza I) were of a similar shape (long, narrow lawns). They differed, however, in the age of their tree cover. Lindens at Żwirki i Wigury Avenue were 20—40 years old and at Woronicza Street 10—20 years old.

Along these two transects, the number of species in elaterid communities declined. In the park at the Cemetery of Soviet Soldiers — Żwirki i Wigury Avenue transect, there were 7 and 6 species on two park plots, 6 species on the streetside plot (Żwirki i Wigury I), and 3 species, including one introduced, on the interlane plot (Żwirki i Wigury II). In the Wierzbno — Woronicza Street transect, there were 5 and 6 species on the two housing estate plots, while 2 and 3 species on the two streetside plots (Tabs 1—3). Differences in the number of species between the corresponding plots of the two transects, smaller for the housing estate and greater for the park, reflect the effect of the type of urban green area. Species composition of wireworm communities is thus largely influenced by the type of adjacent areas.

It has already been stated that the density of soil click beetles on streetside and interlane plots did not depend on the degree of lead pollution, lawn size and width, or on the distance from the lawn centre to the kerb, probably as a result of considerable differences in the amount of soil shading on these sites. As it is indicated by changes in densities along the transects, elaterid densities are affected by the degree of habitat pollution, expressed here as a distance from the source of pollution. Densities on the two streetside plots of both transects, and at the Żwirki i Wigury Avenue also on the interlane plot, were lower than those on the plots more distant from streets (Figs 10 and 11). It is also interesting that densities on the two streetside plots (Żwirki i Wigury I and Woronicza I) were similar (33 and 44 specimens per sq. m, respectively).

Also trophic structure of the community shows a clear pattern of changes along the transects. The proportion of rhizophages increased from the park to street plots due to an increase in the proportion of *A. sputator*, while the proportions of predators and pantophages declined (Figs 12, 13).

CONCLUSIONS

The community of soil click beetles in Warsaw consisted of 16 species. The largest number of species occurred in large urban parks such as Łazienki, an old park with diverse edaphic conditions, developed by transformation of a forest, and the park at the Cemetery of Soviet Soldiers. They were inhabited by 13 species out of the 16 recorded on all the study areas. Other parks, much smaller and closer to the city centre, and green areas of housing estates were inhabited by 11 species. A comparison of the species composition of elaterid communities on different plots showed that some species occurring in central parts of the town were of secondary origin; they could have been introduced with peat or soil from other regions. It is

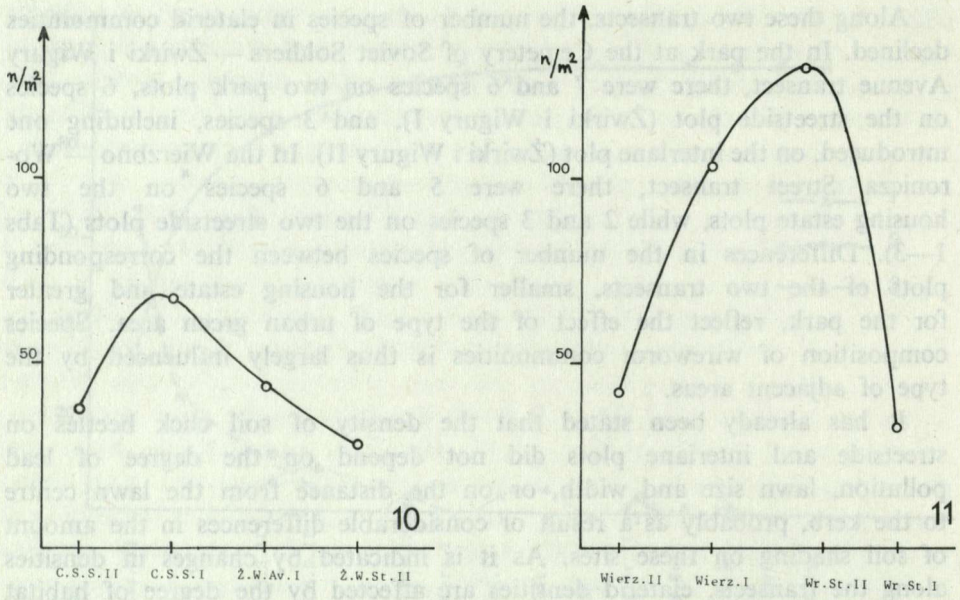


Fig. 10. Changes in the density (numbers of individuals per sq. m) of soil elaterid communities along the Cemetery of Soviet Soldiers—Żwirki i Wigury Avenue transect

Fig. 11. Changes in the density (number of individuals per sq. m) of soil elaterid communities along the Wierzbno—Woronicza Street transect

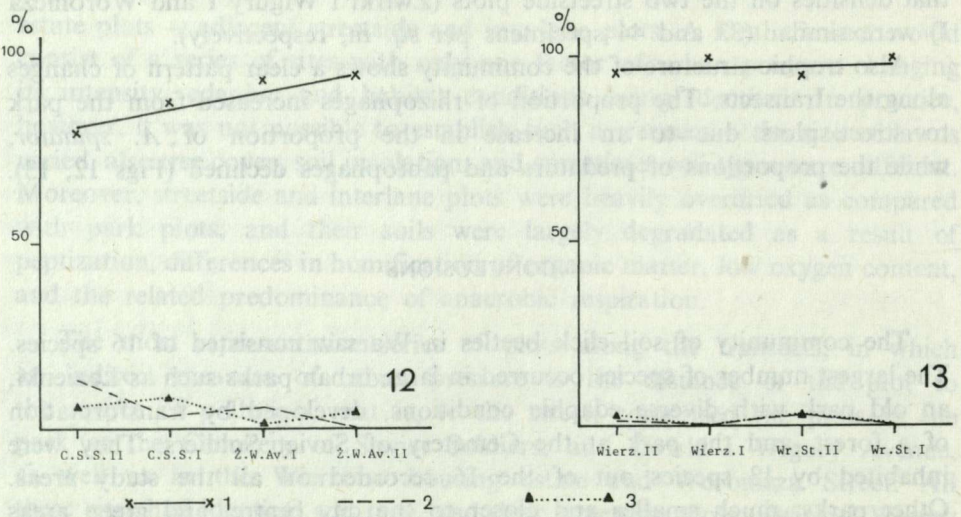


Fig. 12. Changes in the proportion (%) of trophic groups in soil elaterid communities along the Cemetery of Soviet Soldiers — Żwirki i Wigury Avenue transect. 1 — rhizophages; 2 — pantophages; 3 — predators

Fig. 13. Changes in the proportion (%) of trophic groups in soil elaterid communities along the Wierzbno housing estate—Woronicza Street transect. Symbols as in Fig. 12

difficult to identify now all such species, but they certainly include *Dalopius marginatus* on the Wierzbno I and Żwirki i Wigury II plots, also *Adrastus pallens* and perhaps *A. rachifer* on the MDM I plot. Visiting species were represented by *Athous hirtus*. Several specimens of this species were captured by Barber's pitfall traps in central part of the town.

Agriotes sputator, a rhizophagous species characteristic of open habitats, was an absolutely constant member of urban elaterid communities. The group of constant species was also represented by only one species, predatory *Adelocera murina*. The group of accessory species consisted of two rhizophagous species *Agriotes obscurus* and *Adrastus rachifer*. *Agriotes sputator* was also the eudominant species in the communities on almost all study plots, except for the Łazienki Park. On the basis of similarity in dominance structures, two community types were distinguished. One, with *Agriotes sputator* and *Cidnopus pilosus*, was limited to the Łazienki Park. It was similar to the wireworm communities occurring in soils of perennial meadows. The other one, dominated by *Agriotes sputator*, was typical of the other types of urban green areas. These communities were simplified with increasing urban pressure since the accompanying species were eliminated and the proportion of the eudominant species increased.

The density of click beetles in urban parks was about 40 individuals per sq. m, ranging from 33 to 55, while on usually open large lawns in housing estates it could exceed 100 individuals per sq. m. In lawns of closely built-up areas in the city, usually established on rubble soils with sparse sod, the density was very low, less than 10 individuals per sq. m. On the streetside and interlane plots their density largely varied, and no relationship was found between this variation and the degree of pollution with lead, the size of green areas, their width, or distance from the centre to the kerb. It seems, however, that such relationships would have been detected in the absence of large differences between plots in their cover of woody vegetation and the related soil shading. This is implied by the results of the analysis of changes in density along transects: densities were lower close to the pollution source than on more distant plots in parks.

It has also been shown that the species composition of wireworm communities on streetside plots largely depends on the richness of plant species in neighbouring green areas. Only wide streets form an isolating barrier. Elaterid communities on interlane plots are almost uniform, made up of two species (*Agriotes sputator* and *Adelocera murina*, or, less frequently, *Agriotes obscurus*), and in the cases of an extreme isolation of only one species (*Agriotes sputator*).

As it has been shown that the density of soil elaterids depends on the degree of soil shading, the vertical structure of urban green areas

should be properly designed to reduce the number of dominant rhizophages. Trees should be adequately spaced to provide shade.

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STRUKTURA ZGRUPOWAŃ SPRĘŻYKÓW GLEBOWYCH (*COLEOPTERA, ELATERIDAE*) W ZIELENI MIEJSKIEJ WARSZAWY

STRESZCZENIE

W pracy omówiono zmiany składu gatunkowego, liczebności, struktury dominacyjnej oraz profilu zoogeograficznego i ekologicznego zgrupowań sprężyków glebowych pod wpływem

presji urbanizacyjnej. Stwierdzono, że najkorzystniejszymi środowiskami miejskimi dla tych chrząszczy są duże parki, w których występują niemal wszyskie gatunki *Elateridae*, jakie znaleziono w całej zieleni miejskiej Warszawy. W parkach mniejszych i położonych w części śródmiejskiej oraz w zieleni osiedlowej i ulicznej występuje już prawie o połowę mniej gatunków. Ponadto część tych gatunków mogła być wprowadzona sztucznie wraz z ziemią lub torfem, a niektóre gatunki mogą zalatywać do centrum miasta z obszarów peryferyjnych i pozamiejskich. Gatunkiem absolutnie stałym w urbicenozie jest *Agriotes sputator*, gatunkiem stałym *Adelocera murina*. *A. sputator* jest także eudominantem zgrupowań na prawie wszystkich badanych stanowiskach w zieleni miejskiej. W oparciu o analizę podobieństw struktur dominacyjnych wyróżniono dwa typy zgrupowań: zgrupowanie z gatunkami *Agriotes sputator* i *Cidnopus pilosus*, bardzo podobne do zgrupowań z gleb trwałych użytków zielonych, występujące tylko w parku Łazienki Królewskie oraz zgrupowanie cechujące się bezwzględną dominacją *Agriotes sputator*, właściwe dla pozostałych badanych obiektów zieleni miejskiej. W miarę narastania presji urbanizacyjnej następuje degradacja tego zgrupowania, przejawiająca się eliminacją gatunków towarzyszących i wzrostem udziału eudominanta. Wykazano ponadto, że zaplecze w postaci dużego kompleksu zieleni wywiera znaczny wpływ na skład gatunkowy zgrupowań sprężyków na ulicznych stanowiskach przyjezdniowych. Szerokie pasma jezdni są natomiast barierami izolującymi, tak że zgrupowania na stanowiskach międzyjezdniowych są już prawie jednolite, złożone z dwóch, a w skrajnych przypadkach z jednego gatunku. Zagęszczenie glebowych *Elateridae* na trawnikach parkowych i osiedlowych o umiarkowanym zwarciu drzew wynosi ok. 40 osobników na 1 m^2, na odsłoniętych dużych trawnikach osiedlowych w obrębie zabudowy luźnej przekracza 100/1 m^2, natomiast na trawnikach w obrębie zabudowy zwartej wynosi 0—10/1 m^2. Bardzo duże wahania zagęszczenia stwierdzono w zieleni ulicznej — od ok. 10 do 131 osobników na 1 m^2, przy czym nie stwierdzono korelacji między wielkością zagęszczenia a skażeniem ołowiem górnej warstwy gleby, wielkością trawnika, jego szerokością i oddaleniem środka trawnika od krawędzi jezdni. Wpływ na otrzymane wyniki miała niejednorodność badanych obiektów pod względem wielu czynników, zwłaszcza stopnia zacienienia. Na podstawie przebiegu zmian zagęszczenia *Elateridae* w dwóch wybranych układach transektowych stwierdzono, że zagęszczenie zmniejsza się wraz ze wzrostem presji urbanizacyjnej.

СТРУКТУРА СООБЩЕСТВ ПОЧВЕННЫХ ЩЕЛКУНОВ (*COLEOPTERA, ELATERIDAE*) ГОРОДСКИХ ЗЕЛЕНЫХ НАСАЖДЕНИЙ ВАРШАВЫ

РЕЗЮМЕ

Настоящая публикация является продолжением работ по почвенным щелкунам городских зеленых насаждений. В ней обсуждены изменения видового состава, численности, структуры доминации в сообществах и соотношение зоогеографических и экологических элементов под влиянием урбанизации. Констатировали, что на большинстве территорий городской зелении Варшавы в биотопе груда естречается один тип сообщества почвенных щелкунов с доминацией *Agriotes sputator*. Исключение составляет старый городской парк — Лазенки, где встречается сообщество полуприродного характера, в котором доминирует виды *Agriotes sputator* и *Cidnopus pilosus*.