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The shaping of the diversity of invertebrate species in the urban green spaces of Warsaw

Abstract. Two measures are of importance in the analysis of fauna diversity. The species capacity of the environment is defined with the aid of a species-area curve, or through some function of the distribution of the species numbers in the community under investigation. Measures of species diversity (H' and I) give good picture of actual species diversity if they refer to the potential diversity of a site. The Pielou index (J') shows that, in conditions with urbanization pressure, the diversity of the fauna may be either greater or smaller than in the natural environment.

INTRODUCTION

The study of the fauna of urbanized, industralized and agricultural areas has provided a basis for the development of the theory of faunal degradation. According to this theory, human activity deforms natural relationships within a fauna, causes the extinction of some species and threatens others. This is expressed in the decreased species richness of the fauna, and produces in consequence a weakening of the ability of ecological systems to regulate themselves. The result of this is the opening up of urban ecosystems to mass invasions of the pests of plants.

However, on the other hand, it seems obvious that a large forest complex with the character of a nature reserve creates better conditions for the development of a richer species composition than a small lawn near a road, a group of trees within a housing estate, or even a small park with an artificially-formed vegetation structure. All of the latter are likely to be able to accomodate fewer species than the former.

Against the background of these introductory statements, I would like to consider the following question: is the development of a fauna of high species richness possible in the environmental conditions provided by urban green space? A positive answer to this question has a creative character. This is because it allows for a search for circumstances and conditions in which such an increased diversity of fauna – the most mobile component in the structure of urban ecosystems – can be realized.

DEFINITIONS AND MEASURES

An attempt to answer the question above is possible if we accept the division between two concepts which contribute to the determination of the richness of the fauna in a given place. These are:

– the species capacity of the environment,
– the species diversity of the fauna.

Both should be considered from theoretical and methodological viewpoints.

The species capacity of a given environment is defined as the number of species which in reality inhabit it. This means that an empirically-established number of species inhabiting a studied area has been confirmed as correct from the methodological point of view, ie a number of species which have not appeared in sampling have been added, and accidental species – which were caught but which do not inhabit the given area – have been removed. The real number of species may therefore differ from that established empirically, by being either higher or lower. Species capacity may constitute either a defined or undefined quantity, depending on the degree of heterogeneity of the area under study (BALOGH 1958). A general idea of this quantity may be gained even in the initial stages of a study, on the basis of a "species-area" – type curve, which also gives a good basis for the determination of the specifics of an environment in relation to its fauna.

The notion of faunal diversity is defined in many different ways (TAYLOR 1978), while individual definitions are expressed variously in mathematical formulae. For instance, it may be mentioned that, in the first monograph on this problem (WILLIAMS 1964), species diversity (α) gives an indication of the number of species represented in the faunistic material by one individual. The so-called coefficients of species richness relate the number of species ascertained empirically to variously-interpreted sample size. The definitions of diversity mentioned are of little value when carrying out evaluations of the phenomenon under study. I discuss this issue more widely elsewhere (TROJAN 1992). The use of diversity indices based on probabilistic principles (SHANNON, WEAVER 1949, SIMPSON 1949), and for which the standard deviation may be estimated, has therefore been accepted. These two measures give a result which depends on the number of species present in the faunistic complex under study, as well as on the distribution of their numbers.

The dependence of measures of species diversity on species number makes it inevitable that only data from samples with the same, or a similar, number of species are highly comparable. This difficulty may be got round by making use of a coefficient based on measures which define the maximum diversity achievable within an environment's given species capacity. Such proposals – introducing as the measure of diversity the deviation of the observed diversity from the maximum possible or the potential species diversity – were presented by PIELOU (1969)

$$J = \frac{100 \, H'}{H_{max}}$$

With a reference point as constituted by potential species diversity, it is necessary also to consider the question of the unification of both measures of diversity (H' and

I). The direction of the changes in the SHANNON and WEAVER Index (H') is in accordance with the changes in species diversity. Higher diversity of the fauna corresponds to higher values of the index. On the other hand, in the case of Simpson's measure (I), the direction of change is the reverse (PIELOU 1974). Comparison of the values of both indices is easier if use is made of the modified measure from SIMPSON (I')

$$I' = 1 - I$$

in which the course of the changes is in accordance with the changes in the species diversity of the fauna.

The variability range of the values of both measures (H' and I')is contained between two cardinal points (K), delimiting the lower and upper values of the index (K_{min} and K_{max} respectively).

The lower cardinal point (K_{min}) corresponds to the situation in which the faunal group under study is reduced to only one species. Such events occur in the case of extreme pressure on ecosystems. In these circumstances, both:

$$K_{min} (H') = 0$$

and

$$K_{min} (I') = 0$$

Thus application of the transformed index to Simpson's measure ($I' = 1 - I$) has caused the lower cardinal point for both measures to be indentical.

The value of the upper cardinal point (K_{max}) is established differently. For both measures the basis for the calculation is the actual number of species in the group under study (S^*). The destignation of the upper cardinal point makes sense if the empirical and real numbers of species (S and S^* respectively) are close to each other ($S \cong S^*$).

For the SHANNON and WEAVER measure, the upper cardinal point defined by the formula:

$$K_{max} (H') = \log S^*$$

and that for SIMPSON'S measure by $K_{max} (I') = 1 - 1/S^*$

The maximum species diversity for both measures is attained when the probabilities of selecting at random an individual belonging to any one of the species making up the faunal group are equal, ie that:

$$P_1 = P_2 = P_3 .... Ps^*$$

The degree of variability of both measures is contained within limits

$$0 \leq H' \leq \log S^*$$

and

$$0 \leq I' \leq 1 - 1/S^*$$

These are also variability ranges of different magnitude (Fig. 1), because for (H')
the numerical values K_{max} (H'), expressed by indices to the power 10 depend on the
order of magnitude of S* (Tab. 1). On the other hand, numerical values of SIMPSON'S
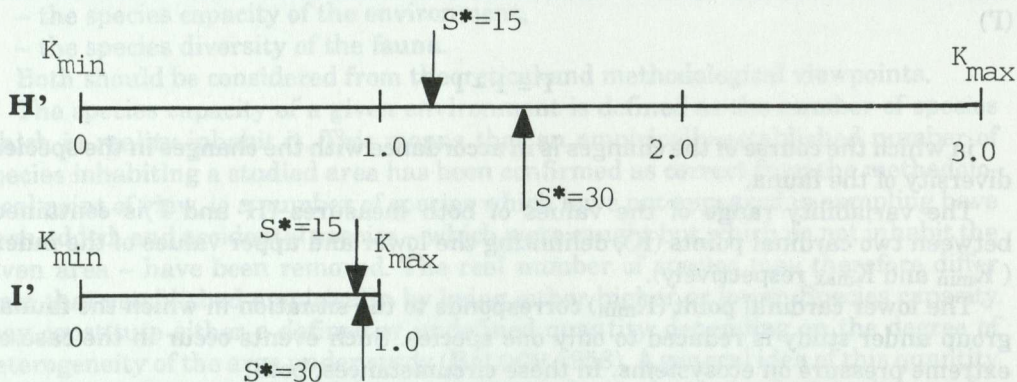measure K_{max} (I') only approach 1 even with very large numbers of species.

Fig. 1. The difference in the position of upper cardinal points on the variability range of the two species
diversity measures (H', I'). The position of (K_{max}) for different (S*) is marked by arrows.

Table 1. Values of the upper cardinal point (K_{max}) for two measures of species diversity (H', I') depending
on the number of species (S*).

S*	K_{max} (H')	K_{max} (I')
0–10	0–1	0.00–0.900
10–100	1–2	0.90–0.990
100–1000	2–3	0.99–0.999
→ 1000 000	→ 6	→ 0.999 999

The evaluation of the differences in the value of the upper cardinal point has great
significance when comparing the diversity of groups of species with 10–20 species or
several tens of species. Such situations are frequent when faunistic research is
limited to only one family of invertebrate animals. For example, when S* values are
small, values for K_{max} are as given below:

for S* = 15; K_{max} (H') = 1.1761, K_{max} (I') = 0.9333;

for S* = 30; K_{max} (H') = 1.4777, K_{max} (I') = 0.9667.

The upper cardinal point designated by SIMPSON'S measure is more stable than is
the case for the SHANNON and WEAVER measure.

The measure of potential species diversity allows for diversity to be estimated in natural environments, and in artificial ones transformed by man to various degrees. It is expressed as a percentage of the potential species diversity. In this paper, it has been applied in seeking to answer the question posed in the introduction: whether it is possible, in urban conditions, to create faunistic systems of higher-than-natural diversity.

SPECIES CAPACITY AND DIVERSITY IN NATURAL AND URBAN ECOSYSTEMS

Sites for the collection of material in Warsaw and its environs were designated on the basis of a transect through environments illustrating increasing degrees of urban pressure. One end of this transect was made up of natural forest ecosystems represented by nature reserves. Urban pressure equal to zero was adopted for these areas. At the other end of the transect is the city centre: the most heavily built-up area with much of the ground surface covered by concrete slabs and asphalt, and with a human population of high density. Maximum urban pressure equal to 1 was adopted for this end of the transect. The remaining sites were represented by intermediate values for this pressure.

The analysis carried out along this transect, and showing the influence of urban pressure on the fauna, has been included in papers published in "Memorabilia Zoologica", which were entitled: "Structure of the fauna of Warsaw; effects of urban pressure on animal communities". Work on the primitive flies in the group *Tabano-morpha* (TROJAN 1981) may serve as an illustration of the trends observed, and characteristic for a considerable number of faunal groups. All the studied trophic groups show a decrease in the number of species with increasing urban pressure. However, this decrease is greater among the groups of animals occupying higher levels of the trophic pyramid of the ecosystems: namely predators and parasities. The smallest decline in the number of species was noted amongst saprophages. STERZYŃ-SKA (1990) was even able to demonstrate that, among such typical saprophages as springtails (*Collembola*), the smallest number of species inhabited the soils of arable land, and the largest number occupied urbanized areas:

lime-oak-horneam-forest   61 species,

meadows and pastures   61 species,

fields and orchards   38 species,

urban green spaces   75 species.

It should therefore be underlined that – in certain faunal groups – the diversity of environmental conditions created with the establishment of urban green spaces may lead to an enrichment of species composition compared to that observed in the homologous natural environment. Another picture of the phenomenon is presented by studies of Warsaw's ground beetles (*Carabidae*) (CZECHOWSKI 1982) as well as synanthropic flies (GÓRSKA 1982). These groups are represented by the greatest number of species in the suburban areas made up of a mosaic of agricultural and urbanized areas with many small gardens.

A separate question is the diversity of fauna along the transect of increasing urban pressure. This has been defined here as the PIELOU index (J') (1969). The general trend observed within the fauna is not correlated with the gradient of urban environmental pressure (Fig. 2). In reality, diversity is closest to the potential
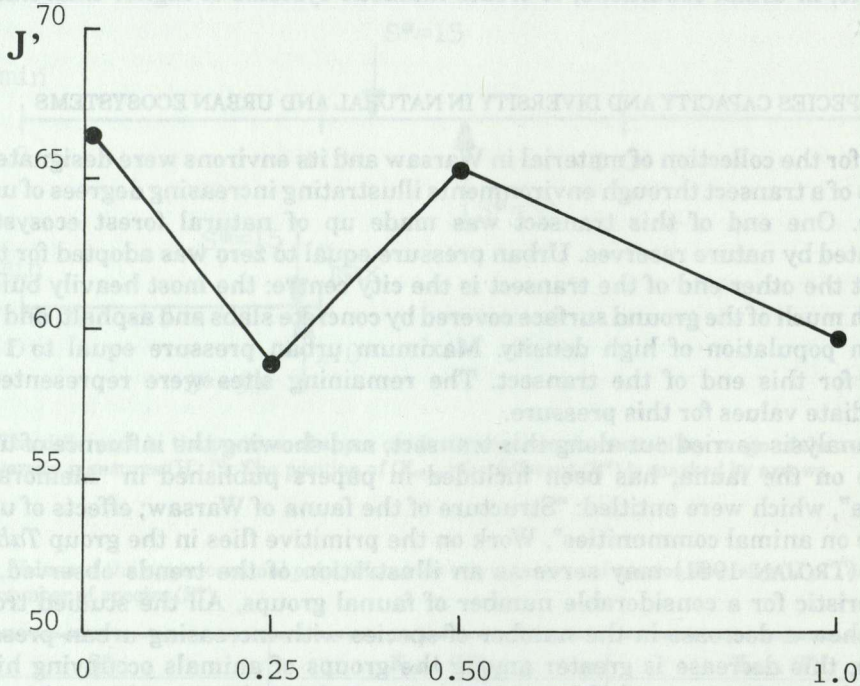

Fig. 2. Changes in the values of the Pielou index (J') calculated for five different faunal groups with increasing urban pressure.

maximum in forest reserves, followed by the garden spaces of housing estates, then the lawns near roads. In last place come the city parks which, in terms of the quality of environmental conditions, are often close to the natural forest. This picture is complicated further (Tab. 2) when we consider separately the data referring to individual faunal groups. Different phagic groups of animals show diversity closest to the potential maximum (ie the most even distribution of individuals across species) at different points along the transect studied. Flying predators (*Sphaecidae*) attain their greatest diversity among housing estate green spaces, sucking phytophages in natural forests, and grazing phytophages – in the same way as edaphic springtails (*Collembola*) – in city parks. An exceptional position is that of the polyphagic ground beetles (*Carabidae*), whose species diversity is closest to the potential maximum in such an environment as the lawns near and between roads: an environment unique in its small area, high degree of isolation and considerable pollution by heavy metals.

From this rather unusual look at data illustrating faunal diversity in a city, it can be seen that there is a need for further analyses to be carried out. It is not merely

necessary to document the negative influence of urban pressures, as expressed through the impoverishment of the species composition of a fauna and the degradation of its structures. A new way of looking at the fauna shows the possibility for high-diversity faunal groups to develop within a city's green spaces. A necessary condition for this is the diversification of the urban environment achieved in the course of building projects in cities. Such a diversification leads directly to an increase in the number of ecological niches and in turn to an increase of the richness of the fauna, and hence to the emergence of systems that are better able to regulate themselves and are more permanent.

Table 2. Values of the Pielou index (J') in natural and urban sites.

Systematic and trophic group	Natural lime-oak-hornbeam forests	Urban parks	Green of housing estates	Streetside green
Sphecidae – predators	78.5 ± 15.2	45.9 ± 24.2	80.2 ± 4.0	52.9 ± 20.3
Homoptera Auchenorrhyncha – sucking phytophages	73.2 ± 9.1	52.2 ± 9.5	62.0 ± 10.2	50.6 ± 11.6
Chrysomelidae – grazing phytophages	73.4 ± 7.6	74.3 ± 6.3	67.0 ± 14.3	74.1 ± 16.2
Carabidae – polyphages	59.7 ± 2.9	69.3 ± 10.0	68.6 ± 7.1	74.1 ± 11.1
Collembola – saprophages	47.4 ± 0.9	52.3 ± 5.7	49.6 ± 7.3	45.7 ± 7.7

REFERENCES

BALOGH J. 1958. Lebensgemeinschaften der Landtiere. Verlag der Ungarischen Akademie der Wissenschaften, Budapest; Akademie Verlag, Berlin.

CZECHOWSKI W. 1982. Occurrence of carabids (*Coleoptera, Carabidae*) in the urban greenery of Warsaw according to the land utilization and cultivation. Memorabilia zool., **39**: 3–108.

GÓRSKA D. 1982. *Anthomyidae, Muscidae* and non-parasitic *Calliphoridae* (*Calyptrata, Diptera*) of Warsaw and Mazovia. Ibidem, **35**: 93–114.

PIELOU E. C. 1969. An introduction to mathematical ecology. Wiley Interscience, New York.

PIELOU E. C. 1974. Population and community ecology. Gordon and Braech Science Publishers, New York.

SHANNON C. E., WEAVER W. 1949. The mathematical theory of communication. Urbana of Illinois Press.

SIMPSON E. H. 1949. Measurement of diversity. Nature, **163**: 688.

STERZYŃSKA M. 1990. Communities of Collembola in natural and transformed soils of the linden-oak-hornbeam sites of the Mazovian Lowland. Fragm. faun., **34**: 165–262.

TAYLOR L. R. 1978. Bates, Williams, Hutchinson – a variety of diversities. Symp. Roy. Ent. Soc. London, **9**: 1–18.

TROJAN P. 1981. *Diptera Tabanomorpha* of Warsaw and Mazovia. Memorabilia zool., **35**: 3–31.

TROJAN P. 1992. Analiza struktury fauny. Ibidem, **47**: 1–121.

WILLIAMS C. B. 1964. Patterns in the Balance of Nature. Acad. Press, London and New York.

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