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Effects of urbanization on the plant cover of Warsaw

Abstract. The paper briefly reports on the main results of studies on plants and plant communities, carried out in Warsaw since 1977. Historical changes as well as major features of present composition and spatial distribution of the flora are summarised. The actual vegetation is characterised with respect to its origin, site-determined differentiation and distribution patterns. The effect of urbanization on plant cover is considered.

INTRODUCTION

Comprehensive geobotanical studies involving floristic and vegetation mapping have been carried out in Warsaw from 1977 onwards. This paper aims to summarise the main patterns of change in plant cover, resulting from the impact of the city.

Warsaw is located in mid-European Lowlands, within the temperate deciduous forest zone. Before the town was founded in the 13th century, the primary forest vegetation had been destroyed over a considerable area and had been replaced by arable land (DROZDOWSKI, ZAHORSKI 1981). Further development of the town has taken place at the expense of the adjacent countryside. Urbanization rapidly increased in the second half of the 19th century, leading to the present agglomeration (with c. 1.6 million people in an area of 485 sq km).

Due to urbanization, the original site conditions have been changed including local climate (KOSSOWSKA 1973), soils (CZERWIŃSKI, PRACZ 1990) and water (see also reviews in BIERNACKI 1990, ZIMNY 1990). Within the current city boundaries, the degree of change ranges from slightly influenced sites on the periphery to man-made sites in the city centre with no relation to the original geology. Vegetation confined to strictly urbanised sites occurs over c.55% of the city, whereas the remaining area is still occupied by pre-urban vegetation of arable land, grassland and forests (Fig.1).

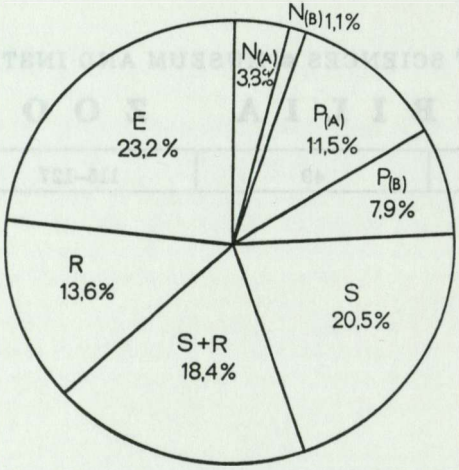

Fig. 1. Spatial proportions of main vegetation types (FALIŃSKI 1969) distinguished in Warsaw with respect to their origin and history. $N_{(A)}$ – near-natural forests and brushwoods, $N_{(B)}$ – near-natural herb communities, $P_{(A)}$ – semi-natural forests and brushwoods, $P_{(B)}$ – semi-natural herb communities, S – segetal vegetation, R – ruderal vegetation, S+ R – segetal complexed with ruderal vegetation, E – subspontaneous vegetation of the city greenery.

FLORA – CHANGES IN HISTORICAL AND SPATIAL DIMENSIONS

The earliest floristic records from Warsaw date back to the 17th century. More floristic data from the town and its surroundings have been collected from different types of habitats from the late 19th century (SUDNIK-WÓJCIKOWSKA 1989). The total number of plant species occurring during the last 150 years was assessed at 1416. The present-day floristic inventory and the distribution charts of each species were based on the studies conducted against a grid of 1.5 x 1.5 km squares in 1977–1982 (SUDNIK-WÓJCIKOWSKA 1987a). The flora of Warsaw consisted of 1109 species (these figures have been supplemented in 1983–1992, to over 1250 species).

The number of species as well as the proportion of particular groups of synanthropic species in the total present-day flora of Warsaw is similar to that found in some other large cities (Fig. 2; see also JACKOWIAK 1990, OLACZEK et al. 1990, PYŠEK 1989, KLOTZ 1990). 70% the present day Warsaw flora is of native species, and 45% of them are species confined to natural and semi-natural communities. It should be noted that about half of these species are considered rare and endangered. The proportion of alien species in the total flora is 30% and the most important group of permanently established recent newcomers (kenophytes sensu KORNAŚ (1968) – 9%.

The analysis of the historical records of flora showed that 134 species became extinct and 60 species were endangered. Analogical data from Poznań: 133 + 45 species (JACKOWIAK 1990) and Berlin: total 250 species (SUKOPP 1990). In Warsaw and Poznań the decline in the overall number of species was accounted for by a reduction in the number of natives over the last 150 years (Fig. 3, 4). Most of these species are associated with moist habitats and rich deciduous forest.

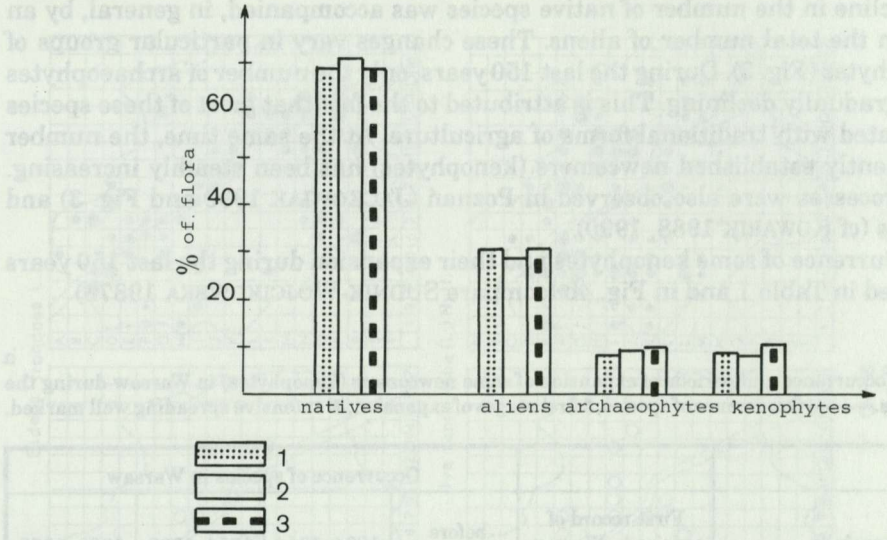

Fig. 2. The proportion of native and alien species in the present-day flora of Warsaw (1), Łódź (2) and Poznań (3).

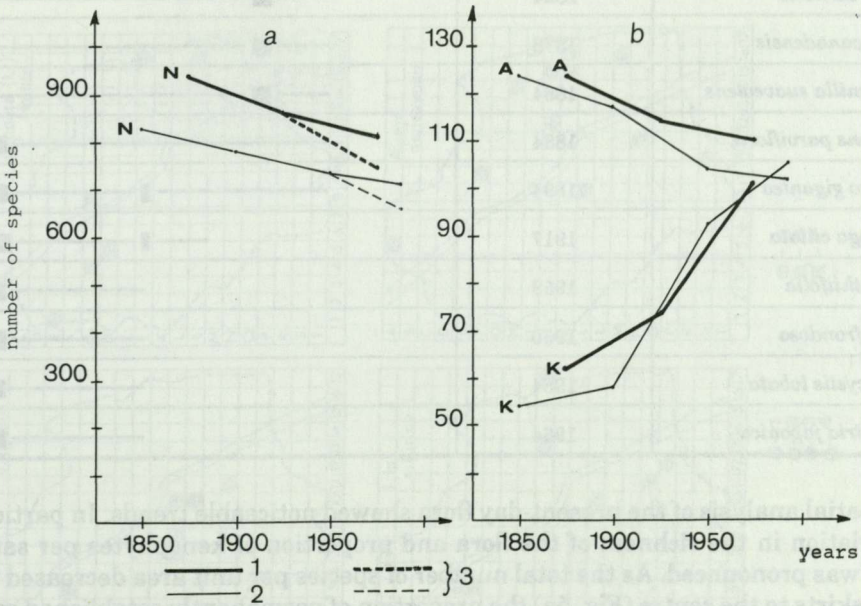

Fig. 3. Changes in the number of native species (N), archaeophytes (A) and kenophytes (K) in the flora of Warsaw (1) and Poznań (2); 3 – species endangered.

The decline in the number of native species was accompanied, in general, by an increase in the total number of aliens. These changes vary in particular groups of anthropophytes (Fig. 3). During the last 150 years, only the number of archaeophytes has been gradually declining. This is attributed to the fact that most of these species are associated with traditional forms of agriculture. At the same time, the number of permanently established newcomers (kenophytes) has been steadily increasing. Similar processes were also observed in Poznań (JACKOWIAK 1990 and Fig. 3) and other cities (cf KOWARIK 1988, 1990).

The occurrence of some kenophytes and their expansion during the last 150 years is presented in Table 1 and in Fig. 4b (compare SUDNIK-WÓJCIKOWSKA 1987b)

Table 1. The occurrence and periods of expansion of some newcomers (kenophytes) in Warsaw during the last 150 years. ——— Occurrence of species, ▮ first stages of expansion, ■ extensive spreading well marked.

Kenophyte	First record of species in Warsaw or province	Occurrence of species in Warsaw			
		before 1824	1824–1914	1914–1939	1939–1982
Acorus calamus	1652	—■	———	———	———
Conyza canadensis	1730	—■	———	———	———
Senecio vernalis	1824		—■	———	———
Elodea canadensis	1878		—■	———	———
Chamomilla suaveolens	1884		—■	———	———
Impatiens parviflora	1884		———	———	■—
Solidago gigantea	1894		———	▮—	■—
Galinsoga ciliata	1917		——	▮—	■—
Iva xanthiifolia	1959			———	■—
Bidens frondosa	1960			———	■—
Echinocystis lobata	1964			———	■—
Reynoutria japonica	1964			———	■—

A spatial analysis of the present-day flora showed noticeable trends. In particular the variation in the richness of the flora and proportion of kenophytes per sample square was pronounced. As the total number of species per unit area decreased from the outskirts to the centre (Fig. 5a) the proportion of permanently established recent newcomers increased (Fig. 5b). The results obtained enable zones of differing degrees of anthropic pressures to be drawn using floristic parameters (SUDNIK-WÓJCIKOWSKA 1988, 1991).

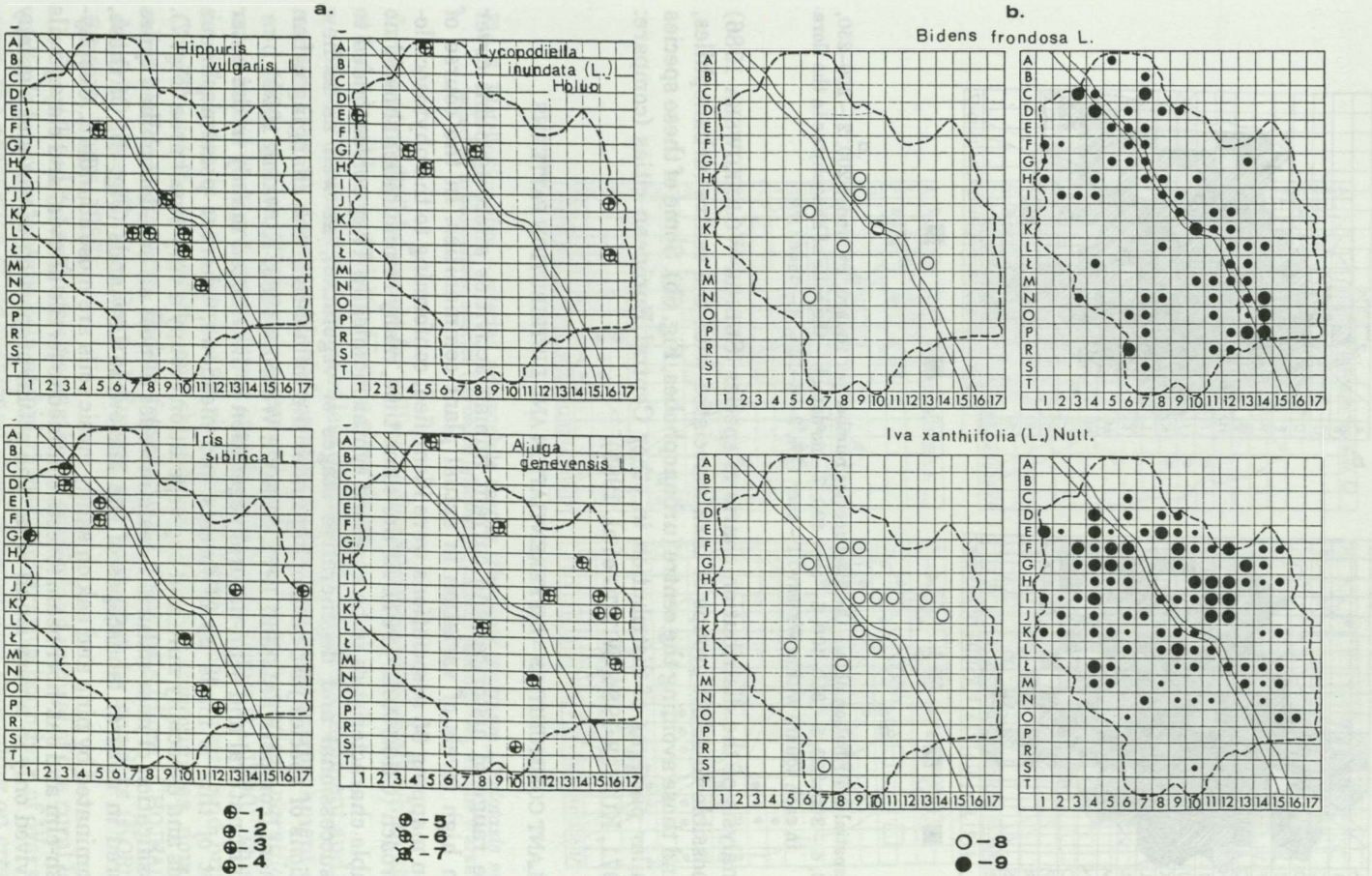

Fig. 4. Changes in distribution of: a – extinct species (*Hippuris vulgaris*, *Lycopodiella inundata*), endangered species (*Iris sibirica*, *Ajuga genevensis*); b – species introduced to Warsaw after World War II and considered increasing newcomers (*Bidens frondosa*, *Iva xanthiifolia*). 1 – 1824–1914, 2 – 1914–1939, 3 – 1939–1971, 4 – 1977–1982. The degree of habitat transformation after the last record of species: 5 – slight, 6 – partial, 7 – intense. Categories of data: 8 – historical, 9 – present-day.

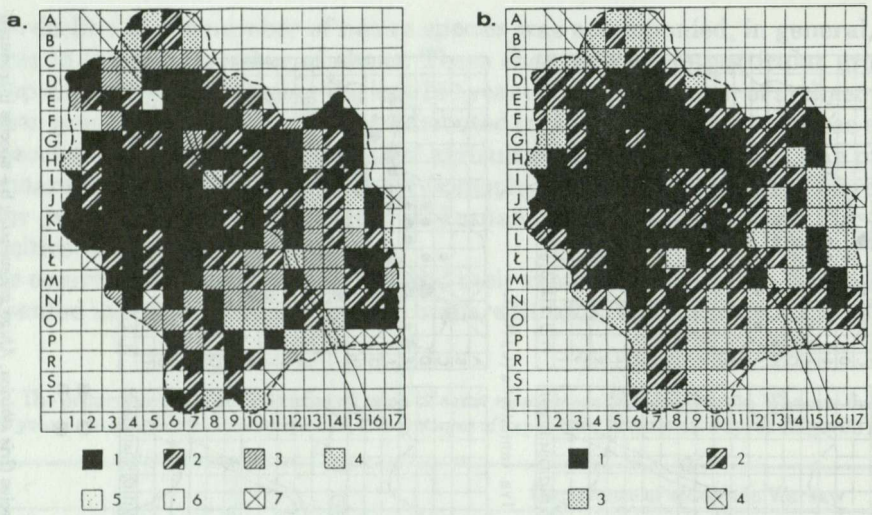

Fig. 5. The spatial distribution of: a – the total species number per square: 1 – under 200, 2 – 200–250, 3 – 250–300, 4 – 300–350, 5 – 350–400, 6 – over 400, 7 – no data; b – the ratio of kenophytes in the flora in each square within Warsaw: 1 – over 12%, 2 – 8–12%, 3 – under 8%.

The analysis of the distribution charts of species (SUDNIK-WÓJCIKOWSKA 1986) made it possible to select groups of taxa associated with the centre (urbanophiles, Fig. 6a) and those avoiding the centre (urbanophobes, Fig. 6b). Some of these species show similar patterns of distribution in other Central European cities (compare: GUTTE 1971, KUNICK 1984, WITTIG et al. 1985).

PLANT COMMUNITIES – DIFFERENTIATION AND DISTRIBUTION PATTERNS

A wide range of historical and current human activities affecting plant cover results in high levels of variation in actual plant communities. In the course of vegetation mapping 85 associations were identified, conforming to the phytosociological approach (CHOJNACKI 1991). At the same time, many communities showed no recognisable characteristics to be assessed syntaxonomically. They corresponded to various successional and degenerative stages of vegetation, as well as to new combinations of species just developing under the influence of the changing urban environment (compare FALIŃSKI 1971, SUKOPP, WERNER 1983, KOWARIK 1990).

Remnant natural and semi-natural vegetation is distributed mainly in the outer city. Most of this is made up of forests and meadows, whereas psammophilous grasslands and especially mire and bog vegetation occupy a very small area (Fig. 7).

A classification of near-natural forests includes almost all site-determined types encountered in natural landscapes of the Mazowsze Lowlands (Fig. 8). Of these, forests dominated by pine and oak on sandy mesic soils are most abundant. Geophyte-rich ash-elm and oak-hornbeam forests confined to fertile alluvial and clayey soils have survived only in a very small area. The actual proportion of wet and swampy

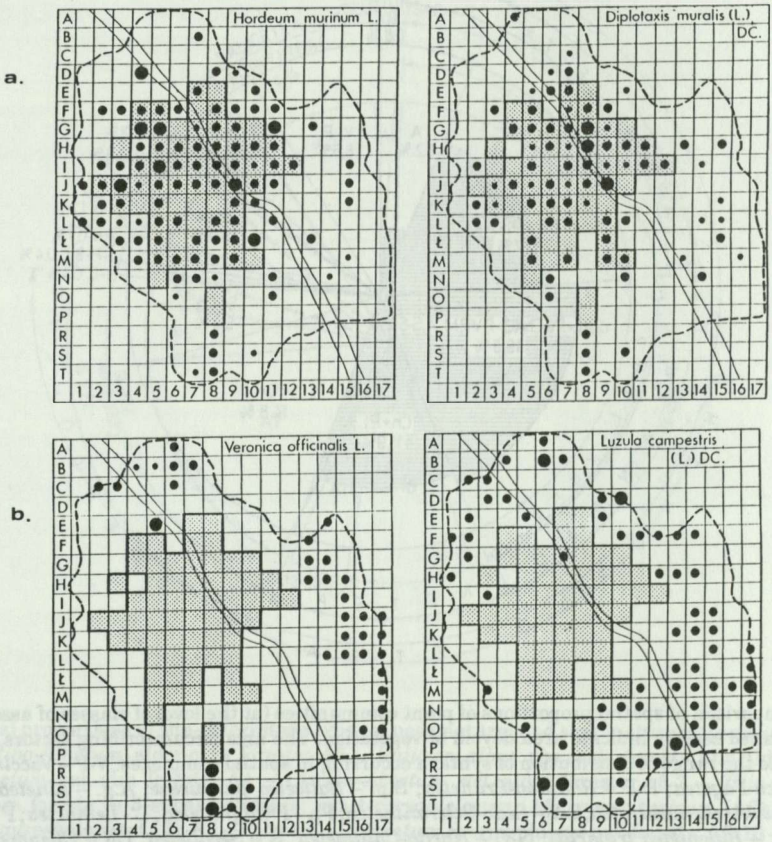

Fig. 6. Distribution of: a – selected urbanophile species (*Hordeum murinum*, *Diplotaxis muralis*); b – selected urbanophobe species (*Veronica officinalis*, *Luzula campestris*) within Warsaw.

forests is negligible, except for willow-poplar forests and thickets which still occupy a considerable area within Vistula river dams.

Most of the forests are more or less disturbed through management and recreational use (Fig. 9). A noticeable deformation to the flora is an encroachment of ruderal and alien species. The most successful invaders (e. g. *Impatiens parviflora*) occur even in the best preserved forest stands (SOLIŃSKA-GÓRNICKA 1990). This increase in neophytes is most marked in riverside *Salicion albae* forests and brushwoods, *Convolvuletalia* macroforbs and short-lived *Bidention* communities, dominated by alien *Solidago gigantea*, *Bidens frondosa* and *Eragrostis pilosa* (CHOJNACKI 1991). Alluvial sites all over Central Europe are wide open to invaders (KORNAŚ 1990, SUKOPP, TREPL 1987).

Short-lived synanthropic vegetation of arable land, typical of the rural landscape, still plays an important role within the administrative boundary of Warsaw. However, the proportion of old-fashioned weed communities depending on crop-rotation

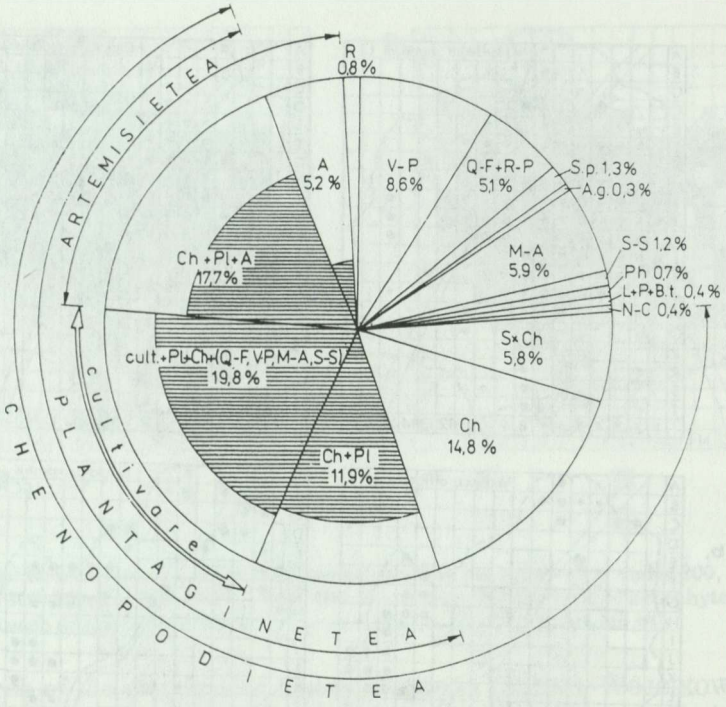

Fig. 7. A comparison of spatial proportions of plant communities (at the level of classes of associations) in Warsaw. Shaded sectors indicate area devoid of vegetation. The arcs circumscribing sectors of the circle correspond to the range of distribution of syntaxa occurring in spatial complexes. V-P – *Vaccinio-Piceetea*; Q-F – *Querco-Fagetea*; R-P – *Rhamno-Prunetea*; S.p. – *Salicetea purpureae*; A.g. – *Alnetea glutinosae*; M-A - *Molinio-Arrhenatheretea*; S-S – *Sedo-Scleranthetea*; Ph – *Phragmitetea*; L - *Lemnetea*; P – *Potamogetonetea*; B.t. – *Bidentetea tripartiti*; N-C – *Nardo-Callunetea*; S – *Secalietea*; Ch – *Chenopodietea*; Pl – *Plantaginetea*; A – *Artemisietea*; R – *Robinietea*.

is very low (Fig. 7). Instead, due to intensive horticulture, rump *Polygono-Chenopodietalia* communities, very close to garden *Galinsogo-Setarietum*, are common. The latter is a basic component of vegetation confined to the open development of the suburbs.

Ruderal vegetation of secondary urban and industrial sites is dominated by early stages of succession, represented by annual *Sisymbrietalia*, perennial and grassland *Onopordetalia*, and trampled *Plantaginetalia maioris* communities. Ruderal scrub and early stage woodland are also encountered on less disturbed city derelict land. Most frequently, they are dominated by native *Sambucus nigra* and North American *Acer negundo* and *Robinia pseudacacia*. Even the most developed forest stages show only weak links with natural forest communities. Further classification of ruderal vegetation can be described only to some extent syntaxonomically (Tab. 2) due to the frequent occurrence of fragmentary developed communities and new combinations of species centring around invading aliens (JANECKI 1983, CHOJNACKI 1991).

As in many European cities, *Tanaceto-Artemisietum* plays the most important role at the association level in terms of area covered (SOWA, OLACZEK 1978). However, a detailed inventory of typological units shows local and regional specificity. In compa-

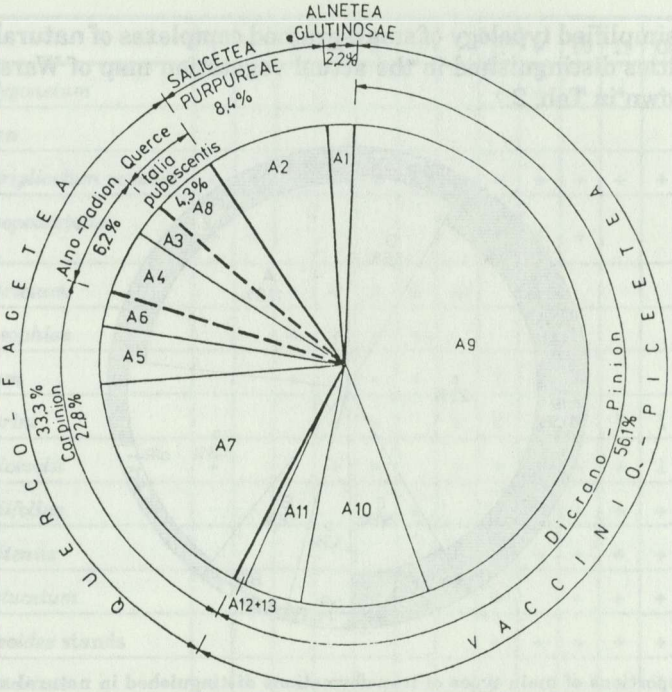

Fig. 8. Spatial proportions of site-determined types of near-natural and semi-natural forests and brushwoods. A1 – *Ribo-Alnetum* alder-carr forests; A2 – *Salicion albae* riverside forests and thickets; A3 – *Ficario-Ulmetum* ash-elm forests; A4 – *Circaeo-Alnetum* wet alder forests; A5-7 – *Tilio-Carpinetum* oak-hornbeam forests in 3 subassociations: moist *corydaletosum* (A5); mesic *typicum* (A6); moderately mesic *calamagrostietosum* (A7); A8 – *Potentillo-Quercetum* thermophilous oak forests; A9-10 – *Querco-Pinetum* oak-pine forests in 2 associations: mesic *typicum* (A9) and moist *molinietosum* (A10); A11 – *Peucedano-Pinetum* mesic pine forests; A12 – *Molinio-Pinetum* wet pine forests; A13 – *Vaccinio uliginosi-Pinetum* bog pine forests.

rison with Berlin (SUKOPP 1990), Warsaw differs among others in the occurrence of subcontinental *Atriplicetum tataricae* and *Ivaetum xanthiifoliae*, and in the lack of *Ailanthus glandulosa* and *Buddleja davidii* thickets.

The vegetation of managed city green areas constitutes a special category. Some old parks enclose true remnants of natural vegetation, much disturbed and modified by enrichment with ornamental and synanthropic species. For the most part, the city green areas are composed of secondary tree stands and artificial lawns. Depending on age, use and care, more or less developed early-stage forest and forest edge structures occur within the tree stands. Similarly, grasslands resembling semi-natural communities may occur within the lawns. In most cases, gradual transitions to typical ruderal communities are found (CHOJNACKI 1990, 1991).

Due to the heterogenous mosaic of urban sites, following the distribution of buildings, transportation corridors and open spaces, most communities in the inner city form small patches interspersed with areas devoid of plant cover. Therefore the actual area covered by ruderal vegetation was assessed at no more than 13% of the

city (Fig. 2). A simplified typology of small-grained complexes of naturally developed plant communities distinguished in the actual vegetation map of Warsaw (CHOJNACKI 1991) is shown in Tab. 2.

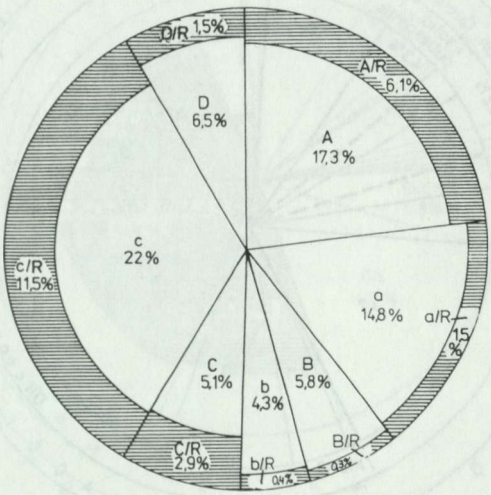

Fig. 9. Spatial proportions of main types of transformations distinguished in natural and semi-natural forests and brushwoods in relation to the total afforested area of Warsaw. A – true near-natural forests; a – forests with simplified stand structure; B – semi-natural pre-forests; b – semi-natural thickets and brushwoods; C – forest plantations with older tree stand; c – artificial young forest plantations; D – forest regeneration complexes; A/R ... D/R – ruderalized forsts and brushwoods.

Table 2. Main types of spatial complexes of urban vegetation distinguished in Warsaw. Spatial proportions of the complex components: +: <5%; 1: 5–10%; 2: 10–25%; 3: 25–50%; 4: 50–75%; 5: 75–100%. Types of complexes in relation to the land use: 1) extensive lawns; 2) old parks and cemeteries; 3) villas with forest remainders on sandy soils; 4) village and suburban open development on sandy soils; 5) village development on loamy and clayey soils; 6) allotments; 7) suburban open development with small gardens; 8) block development with older greenery; 9) recent housing estates; 10) compact block development with scarce greenery; 11) industrial semi-deserts; 12) railway stations; 13) refuse dumps; 14) industrial areas complexed with derelict land; 15) railway embankments of loamy substrates; 16) railway embankments of sandy substrates.

Complex type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Plant cover %	90	90	90	80	80	90	50	30	30	10	10	20	40	80	80	80
Plantaginetea maioris																
Lolio-Plantaginetum	2	+	1	1	1	1	+	1	1	2	1	+	+	1	+	+
Sagino-Bryetum	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Prunello-Plantaginetum		1	+			+		+								
Juncetum macri			+	+												

Complex type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Eragrostio-Polygonetum								+	+	+	+	+				
Chenopodietea																
Chenopodio-Atriplicetum patulae	+	+	+	+	+	+	+	+	+	+	+	+	2	1	+	+
Polygono-Chenopodietalia fragments	+	+						+	+	+						
Galinsogo-Setarietum			4	4	4	5	4									
Sisymbrietum sophiae			+	+	+	+							+	+		
Urtico-Malvetum			+	+	+	+	+	2	1	2						
Hordeetum murini				+	+		+	2	1	2	1	1		+		
Sisymbrietum loeselii	+			+	+		+	+	+	+	+	1	1	+	+	+
Ivaetum xanthiifoliae						+		+	+	+	+	+	2	1		
Atriplicetum nitentis						+	+	+	+	+	+	+	2	1		
Erigeronto-Lactucetum								+		+	+	+				
Eragrostis poaeoides stands								+	+	+	+	+			+	+
Atriplicetum tataricae	+							+	+	+	+	1	+	+	+	+
Poo-Tussilaginetum	+								+		+	+	+	+	+	
Sisymbrion fragments	+	+						+	1	1	2	2	1	1	+	+
Artemisietea																
Eu-Arction fragments	+	+				+	+	+	+	+	+	+	+	+	1	1
Alliarion fragments		1	+	+	+		+	+		+						
Berteroetum incanae	+		+	+					+					1		+
Saponario-Calamagrostietum	+		+	+										1	+	3
Tanaceto-Artemisietum	+	+												2	4	1
Potentillo-Artemisietum			+	+												
Leonuro-Arctietum				1	+	+										
Others																
Lawns related to semi-natural grasslands	1	2	+	+	+	+	+	+	+	+						
Semi-ruderal lawns	2						+	2	3	1	+	+				
Remnant forest structures		1	1													
Pre-forests and brushwoods		2	1	+	+			+		+	+	+			+	+
Artificial park stands		1					+	2	+	+						

Regarding distribution patterns, a group of ruderal plant communities confined to strongly influenced urban and industrial sites (e.g. *Eragrostio-Polygonetum*, *Hordeetum murini*) can be contrasted with those of a suburban-rural type of distribution (e. g. *Galinsogo-Setarietum*, *Potentillo-Artemisietum*, *Leonuro-Arctietum*). Similar regularities were found in other cities (WITTIG, DIESING 1989, SUKOPP 1990).

The analysis of spatial relationships between vegetation units encountered within the entire city area detected essential differences in the distribution patterns shown by vegetation of inner and outer city areas. The former is determined in principle by distribution of the city land uses whereas the latter shows remarkable coincidence with a network of relic natural habitats (CHOJNACKI 1991).

CONCLUSIONS

The effect of urbanization on the plant cover of Warsaw is pronounced both in the historical perspective and when the inner and outer parts of the city are compared. A marked decline of indigenous species and an invasion of aliens during the last 150 years have been followed by the decline and transformation of remnant native vegetation types. On secondary urban sites, completely new combinations of species have been (and are being) established, most often subjected to further alterations.

The increase in man-made disturbance in the historical centre of the city results in floristic poverty and high proportion of aliens, accompanied by prevalence of mosaic-like vegetation structures composed of simple, randomly developed communities. The distribution of the eu-urban vegetation has almost no relationship to the original sites, and the later stages in succession shows only weak links with the natural vegetation.

The pattern of alterations to plant cover, found in Warsaw, conform in general to those recognised in other cities. However, despite man-induced effects common to all cities, a local and regional specificity in floristic and phytosociological inventories can be detected even on strongly influenced sites.

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