THE FLORA OF THE HIGHEST BUILDING IN POLAND (THE PALACE OF CULTURE AND SCIENCE IN WARSAW)

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ABSTRACT

The flora of the Palace of Culture and Science, which is the highest office building in Poland, was analysed. The exterior horizontal surfaces of the building (roofs, terraces, stairs) could be regarded as polyhemerobic habitats. A total of 111 species of vascular plants (native species – 65%) and 6 species of bryophytes were recorded from an area of 16 500 m². It was found that the flora was relatively rich in species, of which some occurred in considerable quantities (over 1000 individuals of such species as: *Eragrostis minor*, *Sagina procumbens*, *Chaenarrhinum minus* were encountered). Moreover anemochorous species dominated (85%) in the flora of the Palace. Thermophilous species and species indifferent to temperature were also strongly represented. The relatively high incidence of hygrophilous species was noteworthy. With regard to life forms an increased proportion of therophytes and phanerophytes (40% and 22%, respectively) was observed. No significant differences were found between the flora of roofs situated on different floors of the building. However, slight differences between the flora of north-facing and south-facing horizontal roof surfaces were marked.

KEY WORDS: synanthropization of flora, polyhemerobic habitats, flora of roofs, flora of Warsaw.

INTRODUCTION

The skyline of Warsaw is dominated by the towering silhouette of the Palace of Culture and Science. The building itself, has aroused some controversy. In the minds of many inhabitants of Warsaw, the Palace of Culture marks a dramatic epoch in the history of Poland. Others regard it as simply the tallest but not the most impressive building in Poland.

From a floristic point of view the Palace of Culture and Science is an interesting subject of research studies. The particular construction and today's poor shape of the building roofs enabled colonisation by plants. The species growing on roofs, terraces and stairs of the building are subject to a variety of environmental constraints, the most frequent of which are related to shortages and excesses in the supply of solar energy, water and mineral nutrients and such stresses as strong winds. Various management practices, including mechanical removal of plants and the use of weed-killers also contribute to the poor development of plants.

The flora of city walls has long been the subject of studies. Floristic inventories made in a number of towns in southern Europe revealed that old walls supported a considerable number of species, of which some were noteworthy. One of the first reports was from a 19th century publication on the flora of Colosseum (Deakin 1885). Further studies devoted to the vegetation and flora of walls included: Segal 1969; Lohmeyer

1975, 1981, 1984; Brandes 1987, 1992, 1995, 1996; Terpó, Balint 1988; Werner et al. 1989; Köhler 1990; Wittig 1991; Celesti Grapow et al. 1993). Vegetation of flat roofs ("Holz-zementdächer") was studied in Berlin (Darius, Drepper 1984). From Poland reports are also available and include: Kostuch (1960), Weretelnik (1973, 1982), Ceynowa-Gieldon (1988, 1994), Świerkosz (1993). In Warsaw the flora developing on the walls of ruins has received much attention (Kobendza 1949; Zanowa 1964).

MATERIAL AND METHODS

Selection of experimental surface areas

The complexity of form of the Palace of Culture made it possible to study areas at different heights in relation to the ground. The areas sampled were situated on different floors of the building (Fig. 1). The surfaces above the viewing terrace were basically inaccessible due to the strong radiation of the transmitting aerial antenna. In the present study large horizontal surfaces with most luxuriant vegetation were chosen for floristic investigations. Altogether 24 experimental surface areas were studied (Table 1, Fig. 1):

- the viewing terrace on the 30th floor which is open to visitors;
- roofs and stairs on top of 4 main towers – 17th floor;

Fig. 1. Palace of Culture and Science: distribution of the areas studied (comp. Table 1).

- the two biggest balconies on the 15th floor;
- flat roofs of the 6-8th floor (including the Congress Hall);
- terraces and stairs at the base of the building.

Evaluation of floristic data

The flora of vascular plants and bryophytes was analysed in the present study. Field investigations were carried out at the height of the growing season (June and August) in 1996 prior to weeding. Two floristic lists were compiled for each sampling area with information on species frequency and incidence

of diaspores. The abundance of species was determined according to 6-grade evaluation scale: 1 – 1-10 individuals; 2 – 11-100; 3 – 101-200; 4 – 210-500; 5 – 501-1000; 6 – >1000. The identification of very young (seedlings) and strongly deformed specimens which had been subjected to environmental stress was extremely difficult. Therefore some specimens were identified up to the rank of the genus only. The following works were used to determine the species: Csapody (1968), Janowski (1972), Król (1972), Aulak (1994), Skrzypczak et al. (1995), Mowszowicz (1979, 1986), Rutkowski (1998). The nomenclature of plant species followed Rothmaler (1988).

A comparative analysis of the flora of the Palace and its immediate surroundings was conducted. Thus a sample area (square) of 1 km² had been chosen which included a central square called Plac Defilad. In some cases floristic data obtained from the Warsaw area in the years 1977-1997 were used (Sudnik-Wójcikowska 1987, 1998). The flora of the Palace was analysed with respect to:

- frequency and abundance of particular species,
- dispersal strategies of species,
- spectrum of life forms,
- groups of species distinguished in the geographical-historical classification of Kornaś (1981),
- requirements of species for light (L), temperature (T) and moisture (F) based on Ellenberg's indicator values (1979).

Floristic lists drawn up for south and north-facing horizontal roof surfaces of the Palace, having an identical total surface area (4200 m² each), were compared to determine the effect of exposure on the wall-dwelling flora. Two groups of areas situated on different floors of the building were distinguished:

- terraces and stairs on the ground floor (0 m above the ground, total surface area – 5700 m²);
- towers and balconies (64 m and 57 m above the ground, respectively, total surface area – 1200 m²).

In this study the viewing terrace (116 m above the ground level, total surface area – 1300 m²) was not considered due to very strong anthropogenic influence.

TABLE 1. Characteristics of the areas studied.

No	Area studied	Exposition	Height above ground level [m]	Surface area [m ²]
1.	Viewing terrace (W)		116	1280
2.	Tower NW (Tnw)	N-W	64	294
3.	Tower WS (Tws)	W-S	64	294
4.	Tower SE (Tse)	S-E	64	294
5.	Tower EN (Ten)	E-N	64	294
6.	Balcony N (BN)	N	57	20
7.	Balcony S (Bs)	S	57	20
8.	Flat roof Iva	N	29	338
9.	Flat roof Ivb	S	29	338
10.	Flat roof Va	N	29	444
11.	Flat roof Vb	S	29	444
12.	Flat roof G1	W-S	25	1307
13.	Flat roof K7	W	27	1195
14.	Flat roof K4	W	26	240
15.	Flat roof K6	W	20	226
16.	Flat roof K2	W	20	360
17.	Flat roof C3	E	20	366
18.	Flat roof D4	N-W	20	1292
19.	Flat roof G4	W-S	20	1269
20.	Flat roof Z4	E-N	20	520
21.	Ground floor (Pn)	N	0	1451
22.	Ground floor (Pw)	W	0	1895
23.	Ground floor (Ps)	S	0	1451
24.	Ground floor (Pe)	E	0	859

Documentation on the Palace of Culture and Science

The information on the history, location and immediate surroundings of the Palace of Culture was obtained from the Main Geodetic and Cartographic Documentation Center, Head Office of Geodesy and Cartography and from descriptions concerning the green areas around the building (Rabiński et al. 1991).

Data regarding the physical and chemical composition of the subsurface construction of the roofs were extracted from the work of Wiślicki et al. (1957) and original blueprints, and were supplemented by the staff of the Palace and the author's own observations.

Information concerning the local climate was obtained from the papers of Kossowska (1961), Stopa-Boryczka (1992, 1995), Wawer (1994) and from the Atlas of Warsaw (1996).

Data regarding air pollution in the city centre were based on the results of surveys carried out in four monitoring stations on pollution concentrations closest to the Palace of Culture and located 300-1000 kilometres away in a straight line (Pietrzak 1993, 1994; Sosnkowski and Golecki 1997; Sosnkowski 1998) and on findings of Okołowicz and Kaczorowska (1970).

THE STUDY AREA

The Palace of Culture and Science and its surroundings

The Palace of Culture was open to the public in 1955. It had been built in the centre of Warsaw in the most destroyed part of the city (Złota, Chmielna, Wielka street). The building is over 231 metres high with a cubature of 817 000 m³. It is located on a postglacial plateau approximately 2 kilometres away from the left bank of the Vistula (Morawski 1980), built at altitude of 112 metres (whereas Śródmieście is located at average altitude of 115 meters, Nowak and Śmierczalska 1972; Atlas of Warsaw 1975).

The Palace of Culture is a free standing building in a densely built area of the city. Open space around the building amounts to 228 000 m² and is lined by streets with high traffic, markets, parking and a central square called Plac Defilad. Most of the area surrounding the Palace is occupied by green areas: lawns and a park. Among the 60 species of trees and shrubs cultivated in the immediate vicinity of the Palace some are over 80 years old; in the early 1950's 40 year-old trees were planted (Wiślicki et al. 1957, Rabiński et al. 1991).

Natural conditions in the vicinity of the Palace of Culture and Science

The local climate prevailing in the district Śródmieście is typical of large urban areas. The phenomenon of urban heat island is observed in the central part of Warsaw, which is the warmest region of the city (Stopa-Boryczka 1992; Wawer 1994; Bogucka 1998). The mean annual temperature in the area discussed is higher by 0.8°C in comparison with the suburbs. According to the Atlas of Warsaw 1996 the average deviation of extreme temperatures during the warm period amounts to 1.5°C compared with the temperatures measured at Okęcie (suburban area).

The specific twenty-four hour change in temperature consist mainly in the decrease of diurnal range of temperatures, particularly in the area of dense building. In the afternoon the temperature in the city centre is often lower. This phenomenon results from thermal inertia of the walls of buildings, larger of shaded area, irregular and often slower heating of road surfaces made up of various materials (Stopa-Boryczka 1992; Wawer 1994).

Aerosols and particulates emitted into the atmosphere constitute the core of water vapour condensation and influence precipitation resulting in the increase of cloudiness and precipitation and the decrease of air humidity and wind velocity. The urban heat island and multi-story buildings contribute to the strong convection and intensive turbulent upward motion of air (Stopa-Boryczka 1992).

Climate conditions vary depending on the location of areas above the ground level due to considerable height of the Palace. However vertical temperature differences are slightly marked up to the level of 60 metres (Kossowska 1961).

The level of air pollution in the immediate vicinity of the Palace of Culture and Science is very high. Average annual means of concentrations of sulphur dioxide, nitrogen dioxide and suspended particulates measured in monitoring sites located in the immediate surroundings often exceed air quality standards and they are determined as the highest means in the whole city (Pietrzak 1993, 1994, Sosnkowski, Golecki 1997, Sosnkowski 1998). The Palace of Culture and Science is located close to busy streets and intersections, where motor transport constitutes the most substantial source of pollution. Approximately 4000 vehicles per hour pass along Al. Jerozolimskie in the rush hours on week-days (Sosnkowski 1998). Average annual means of concentrations of air pollutants from transport sources (measured at the level of 8 meters above Al. Jerozolimskie) often exceed permissible standards (Pietrzak 1993; Sosnkowski and Golecki 1997; Sosnkowski 1998). Urban transport can also have an effect on substratum accessible to plants. Both specks of sand and particulates coming from the surfaces of old roads are found in the air (Okołowicz, Kaczorowska 1970).

The area studied was assigned to the zone of strongest anthropopressure intensity (zone A, Sudnik-Wójcikowska 1987). Such phenomena as overdrying, pollution and acidification of soil are strongly marked and at least 30 per cent of the area is completely inaccessible to plants.

The Palace of Culture and Science: architecture and construction

The architecture of the Palace of Culture is complex – it is a group of volumes, different in size and height (Fig. 1). Every volume has a flat roof, with brick parapet walls at the perimeter, forming an 1.5 m high "attic".

All of the flat roofs have a similar construction. They are all covered with concrete slabs, preventing mechanical damage of the roof itself. The slabs are set on asphalt and the joints are filled with bitume. The slabs contain marble gravel and are because of that severely damaged by the weather conditions. The layers of bitume textile and asphalt are equally crushed, forming a surface favourable for seed germination. Two inches below the surface there is a waterproof layer. Rain water is supposed to drain down on the inclined subsurface straight to the drain pipes. Presently this system of water evacuation is not working properly – the drains are clogged, the waterproof layer is broken and therefore not continuous. Covered roof terrace has many waterproof layers with a topping of ceramic tiles fixed by cement mortar. Terraces and stairs on the lower parts of the building are granite slabs on a thick layer of cement mortar on top of a watertight insulation over concrete construction elements. Only basic repairs are being done to the flat roof areas because of lack of funding, resulting in the poor condition that is seen on the sites being studied.

RESULTS

The flora of the Palace of Culture and Science

The area of 16 500 m² yielded 111 taxa of vascular plants (Table 2A). Preliminary studies of the bryophyte flora revealed that the number of species (6) recorded in the area studied was fairly low. It is interesting to note that half of these species were represented in most of the areas sampled (Table 2B).

Previous studies showed that the total number of species reported from the Warsaw area (430 km²) amounted to 1313, whereas in the immediate vicinity of the Palace (an area of 1 km²) only 198 species of vascular plants were noted. Among the latter, 77 taxa were encountered on the horizontal roof surfaces of the Palace as well as in its vicinity (Sudnik-Wójcikowska 1987, 1998).

A detailed analysis of the flora of vascular plants in the areas sampled showed that the number of species ranged from 1 (viewing terrace W) to 51 (ground floor, north side of the building Pn). It appeared that there was no linear increase of species with the size of the area (Fig. 2). Large areas rich in species could be distinguished at the base of the building (Pn, Pw, Ps, Pe) and on horizontal roof surfaces 27 m above the ground level (D4, G4, K7). On the other hand the flora of small surface areas of balconies (Bn, Bs) and the roof (G1) as well as that of the viewing terrace of the Palace was poor in species.

About 85% of the flora was represented by several individuals only. In the case of five species, however, the number of individuals ranged from 500-1000 (Table 2A). Only three species were represented by more than 1000 individuals. It was also found that the frequency of 85 taxa (77% of the flora of the Palace) did not exceed 25% (they were noted in less than 6 sampling areas). None of the species was recorded in all the areas studied. Only one species occurred with a frequency of about 75% (*Sagina procumbens* represented by more than 1000 individuals). The other 7 taxa (*Chaenarrhinum minus*, *Eragrostis minor*, *Galinsoga ciliata*, *Poa annua*, *P. compressa*, *Populus x euramericana*, *Rorippa palustris*) were frequently encountered in the area studied and were very abundant (Table 2A). The first two species were represented by more than 1000 individuals, the other 5 – by at least 500.

Families containing the highest number of species are presented in Table 3. From the table it is clear that the flora

Fig. 2. The area (m²) and richness of flora of the area studied (comp. Table 1).

Fig. 3. The spectrum of life forms:
A – in the flora of the Palace of Culture and Science;
B – in the flora of the adjacent area (1 km²).

of the Palace is more strongly represented by Salicaceae (*Populus* and *Salix* species) than the flora of Warsaw and the immediate surroundings of the Palace.

With respect to life forms the Palace of Culture supported a high number of therophytes (40% of the flora) and perennials (38%), among which hemicryptophytes prevailed (Fig. 3A). The majority of therophytes grew abundantly in the area studied. Twelve species were represented by more than 100 individuals. Among therophytes, the proportion of species represented by several individuals was 53%, whereas in the case of hemicryptophytes and phanerophytes the percentage of species was assessed at 77% and 79%, respectively.

Perennials comprised about 50% of the flora of Warsaw and the immediate surroundings of the Palace. In the area studied their number was much lower. A relatively small number of perennials was attributed to the specific physical composition of the subsurface, which did not favour the persistence of resting vegetative organs through winter. On the roofs the soil stratum was extremely thin (max. about 6 cm). On the stairs and terraces at the base of the building the plants grew only in the crevices between the granite slabs. Plants were practically absent from the viewing terrace. Moreover mechanical removal of plants and the use of weed-killers also hampered the growth of weeds.

Trees and shrubs made up 22% of the flora of the Palace. The contribution of phanerophytes to the flora of the immedi-

TABLE 2. Taxa noted on the exterior horizontal surfaces of the Palace of Culture and Science in Warsaw.

Life f. – life form: C – chamaephyte, G – geophyte, H – hemicryptophyte, N – nanophanerophyte, P – phanerophyte, T – therophyte. Status – (origin and degree of naturalization): Ap – apophyte, Ar – archaeophyte, Ep – epocophyte, Ef – ephemerophyte, Eg – ergasiophygophyte. For other abbreviations see Table 1. A – Vascular plants, B – Bryophytes.

A.

Taxon	W	Tnw	Tws	Tsc	Ten	Bn	Bs	IVa	IVb	Va	Vb	Gl	K7	K4	K6	K2	C3	D4	G4	Z4	Pn	Pw	Ps	Pe	Life f.	Status
<i>Acer negundo</i> L.							1	1		1				1											P	Ag
<i>Acer pseudo-platanus</i> L.					1																			1	P	Ap
<i>Achillea millefolium</i> L.											1						1				1			1	H	Ap
<i>Agropyron repens</i> (L.) P. B.										1							1								G	Ap
<i>Agrostis tenuis</i> Sibth														1											H	Ap
<i>Amaranthus lividus</i> L. var. <i>ascendens</i> (Lois.) Thell.																				1			1		T	Ep
<i>Anthrrium majus</i> L.																							1		T	Eg
<i>Arabidopsis thaliana</i> (L.) Heynh.																				1	1	1			T	Ap
<i>Arenaria serpyllifolia</i> L.												1	2		1	1			2				1		TC	Ap
<i>Artemisia vulgaris</i> L.									1		3						1		3		1		1	1	HC	Ap
<i>Asplenium ruta-muraria</i> L.																								1	H	Ap
<i>Berteroa incana</i> (L.) DC.	1																								TH	Ap
<i>Betula pendula</i> Roth		1		2	2					1				1				1			1	1		2	P	Ap
<i>Calamagrostis epigejos</i> (L.) Roth										1	1		2				1	1							GH	Ap
<i>Capsella bursa-pastoris</i> (L.) Med.				1							1			1				2			2		1	1	T	Ar
<i>Cardamine hirsuta</i> L.																					1	2			TH	Ep
<i>Cardaminopsis arenosa</i> (L.) Hayek																							1		HC	Ap
<i>Cerastium holosteoides</i> L.																		2		1			1		CH	Ap
<i>Cerasus vulgaris</i> Mill.																				1					P	Eg
<i>Chaenarrhinum minus</i> (L.) Lange				1				2		4	2	1	3	3	3	3	3	3	3	3	1	1		1	T	Ep
<i>Chamomilla suaveolens</i> (Pursh) Rydb.																	1				1			1	T	Ep
<i>Chenopodium album</i> L.		2	1	2	2		1	2			1		2		1			1				2	2		T	Ap
<i>Chenopodium glaucum</i> L.														1										1	T	Ap
<i>Chenopodium murale</i> L.																							1		T	Ar
<i>Chenopodium rubrum</i> L.											1				2	1		2	1		1	1	1		T	Ap
<i>Cirsium arvense</i> (L.) Scop.					1					1											1	1			G	Ap
<i>Conyza canadensis</i> (L.) Cronquist			1	1	1			1			2		1	1		1	2	2		1	1		1	1	TH	Ep
<i>Crepis tectorum</i> L.													1							1					TH	Ap
<i>Dactylis glomerata</i> L.																					1				H	Ap
<i>Digitaria sanguinalis</i> (L.) Scop.																					1			1	T	Ar
<i>Epilobium adnatum</i> Griseb.										1	1						1	1		1					HC	Ap
<i>Epilobium obscurum</i> Schreber					1			2	1	2	1			1		1	3	1		1	2	1			HC	Ap
<i>Epilobium palustre</i> L.								1	1		1														H	Ap
<i>Epilobium parviflorum</i> Schreber															1			1							HC	Ap
<i>Epilobium</i> sp.		2	2	2	2	1		2	1	3	1		1								2	2	1	2	HC	Ap

TABLE 2. cont.

B.

Taxon	Tnw	Tws	Tse	Ten	Bs	IVa	IVb	Vb	K7	K4	K2	C3	D4	G4	Z4	Pn	Ps	Pe
<i>Bryum argenteum</i> Hedw.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
<i>Bryum capillare</i> Hedw.		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1
<i>Bryum caespiticium</i> L.						1						1	1			1		1
<i>Ceratodon purpureus</i> (Hedw.) Brid.	1				1	1		1	1	1	1	1	1	1		1	1	1
<i>Ceratodon purpureus</i> (Hedw.) Brid. fo. <i>brevifolia</i> (Milde) Mnk.			1							1	1							1
<i>Funaria hygrometrica</i> Hedw.																1	1	1

TABLE 3. Families represented by the highest number of species in the flora of the Palace of Culture and Science and in adjacent areas (in brackets number of species per family).

Families most abundant in species		
in the flora of the Palace [0.16 km ²]	in the flora of the immediate vicinity of the Palace [1 km ²]	in the flora of Warsaw [430 km ²]
Asteraceae (24)	Asteraceae (30)	Asteraceae (180)
Poaceae (15)	Poaceae (21)	Poaceae (118)
Salicaceae (11)	Brassicaceae (16)	Brassicaceae (86)
Brassicaceae (10)	Fabaceae (13)	Rosaceae (86)
Rosaceae (5)	Rosaceae (5)	Fabaceae (82)

ate surroundings of the Palace was less appreciable (Fig. 3B). As in the case of the flora of Warsaw their proportion did not exceed 10%. It should be emphasized, however, that the trees and shrubs recorded on the horizontal roof surfaces of the Palace were represented exclusively by seedlings and juvenile specimens.

With regard to origin and degree of naturalization, the dominance of native species was recognized. The majority of species persisting in such heavily disturbed habitats (Fig. 4) were native synanthropes (65% of the flora of the Palace). Among aliens, species which have become permanently established in anthropogenic habitats prevailed (the percentage of archeophytes and epocophytes was identical) and comprised 23% of the flora of the Palace. Some of the ergasiophytes occurring on the horizontal roof surfaces of the Palace (10%) produced tasty edible fruits. Others have probably escaped from flower pots and lawns at the base of the building. These included: *Anthrrium majus*, *Sedum spurium*, *Tagetes patula*, *Thuja occidentalis* and *Taxus* sp.

Comparative analysis of Ellenberg’s ecological indicator values (1979) showed that the flora of the Palace was quite strongly represented by higrophilous species. Thirteen species with moisture indicator values $F \geq 7$ (Fig. 5) made up 12% of the total number of species. Among them were: *Epilobium palustre*, *E. parviflorum*, *Juncus bufonius*, *Phragmites australis*, *Rorippa palustris*.

The frequency distributions of indicator values for light L (Fig. 6) revealed that species showing higher requirements for light ($L > 7$) comprised 67% of the flora of the Palace. Thermophilous species with temperature indicator values $T > 6$ contributed 23% to the total number of species. It was found that species indifferent to temperature were strongly represented (41%) in the flora (Fig. 7). However the percentage of species indifferent to light or moisture conditions did not exceed 10%.

Fig. 4. The percentage of historical-geographical groups of species: A – in the flora of the Palace of Culture and Science; B – in the flora of the adjacent area (1 km²).

Flora of the south- and north-facing roof surfaces of the Palace

An analysis of the flora of the south- and north-facing horizontal roof surfaces revealed differences in the number of species (Fig. 8). The north-facing side of the building supported 82 species, which were represented by less than 500 individuals. On the south-facing roof surface of identical size the number of species recorded was considerably lower (65), with two species represented by more than 500 individuals (*Eragrostis minor* and *Galinsoga ciliata* – heliophilous and thermophilous species usually inhabiting dry habitats, were also encountered on the north side but both species occurred less abundantly). It is notable that 54 species were recorded on both sides of the building.

The contrast between the habitat conditions prevailing on the north and south-facing horizontal surfaces of the building was clearly marked when the frequency of particular life

Fig. 5. Frequency of Ellenberg's indicator values for moisture F: Total – in the flora of the Palace of Culture and Science; North – in the flora of the northern side of the building (for 17 taxa indicator values are not available); South – in the flora of the southern side of the building (for 9 taxa indicator values are not available); [x – taxa indifferent to moisture].

Fig. 6. Frequency of Ellenberg's indicator values for light L: Total – in the flora of the Palace of Culture and Science; North – in the flora of the northern side of the building (for 17 taxa indicator values are not available); South – in the flora of the southern side of the building (for 9 taxa indicator values are not available); [x – taxa indifferent to light].

Fig. 7. Frequency of Ellenberg's indicator values for temperature T: Total – in the flora of the Palace of Culture and Science; North – in the flora of the northern side of the building (for 17 taxa the indicator values are not available); South – in the flora of the southern side of the building (for 9 taxa the indicator values are not available); [x – taxa indifferent to temperature].

Fig. 8. The comparison of the flora of the northern and southern side of the Palace of Culture and Science.

forms was analysed. In sites exposed to the north, the proportion of annuals, perennials and woody species was about 42%, 36% and 22%, respectively. On the south-facing roof surfaces an increased representation of annuals (46%) and perennials (40%) was noted, whereas the frequency of trees and shrubs decreased to about 14%.

A comparative analysis of light, temperature and moisture indicator values for flora of roof surfaces on the north and south side of the building revealed slight differences in species composition and were more considerable when the abundance of species was considered.

Flora of roof surfaces situated on different floors of the building

The total roof surface on top of the towers and balconies (at the level 57 and 64 m) is smaller than the ground floor areas. Therefore, it was not possible to compare the flora of both areas with respect to species richness. Thus the proportion of life forms and historical-geographical groups of species were considered. It was demonstrated that the percentage of therophytes and phanerophytes recorded on upper floors increased by 3% and 5%, respectively. However, the spectra of the historical-geographical groups of species were almost identical.

Dispersal mechanisms

About 85% of the flora of the Palace of Culture was represented by species producing light diaspores adapted to wind dispersal. Perhaps this was attributable to the action of air currents (the fact that air currents aided the dispersal and establishment of the diaspores of these species on roof surfaces of the building). The high incidence of diaspores of *Acer pseudo-platanus* on a roof surface 64 m above the ground was noteworthy.

Species with minute ("dust") diaspores, which are dispersed by wind may also exhibit epizoochory. The roofs of the Palace are spatially isolated units and these sites are regularly visited by birds only.

The diaspores which are dispersed through the action of birds and winds can travel long distances. This is of relative importance for species which were rare or absent from the inner Warsaw area, but were found growing on the roofs of the Palace. Among them were such higrophilous species as: *Epilobium palustre*, *E. parviflorum*, *Phragmites australis*, *Typha* sp. and some species of the genera *Salix* and *Rorippa*. Their diaspores may have been introduced from the riverbanks of the Vistula from a distance of at least 2 km from the Palace.

Some diaspores originated in the area studied with discarded rubbish from the windows of the Palace (e.g. a pine cone found on the roof 29 m above the ground). It is probable that such species as: *Cerasus vulgaris*, *Malus domestica*, *Prunus domestica*, *Prunus cerasifera* and *Lycopersicon esculentum*, which produce tasty fleshy fruits have reached these sites in the same way. In the case of such species as *Solanum nigrum*, *Sambucus nigra* and *Taxus* sp., which also have fleshy diaspores, birds were probably the major dispersal agents.

DISCUSSION

The Palace of Culture as a polyhemorobic habitat

The hemeroby concept was first introduced by Jalas (1955) and subsequently modified by other authors (e.g. Sukopp 1969, 1972; Blume, Sukopp 1976; Kowarik 1988; Jackowiak 1993). Habitats which are subject to a stronger human impact are referred to as polyhemorobic and metahemorobic habitats. As a result of strong anthropopressure metahemorobic habitats are almost devoid of vegetation. On the other hand in polyhemorobic habitats the interference of man is less strongly marked and therefore some species can be found growing, e.g. on railway sides, tram-lines, mine spoil heaps, waste dumps, pavements, town squares as well as on city walls.

The surfaces investigated on the Palace of Culture were also recognized as polyhemorobic habitats. With regard to habitat conditions the surfaces on upper floors are spatially isolated units. Local differences in moisture content are also marked.

Floristic richness

It would appear that the total number of vascular plants (111 species) reported from the Palace (0.0165 km²) is relatively high as opposed to the number of species noted in the immediate vicinity of the building (198 species in an area of 1 km²) and within Warsaw area (1313 species in an area of 430 km²; Sudnik-Wójcikowska 1987, 1998). Similar observations regarding the high diversity of flora of city walls were made by Świerkosz 1993 (in Wrocław – 146 taxa) and by Brandes (1992), who compiled a list of wall-dwelling species from western and southern Europe (e.g. the city walls in Kempen and Zons supported 116 species). The same author (Brandes 1996) recorded 149 species in 16 experimental surface areas (on the ruins of castles in the Harz mountains) and indicated that horizontal walls supported a higher number of species than vertical wall surfaces.

In other polyhemorobic habitats, e.g. industrial and mine spoil heaps in Upper Silesia (Rostański 1998), the number of species recorded was about 100 in sampling areas ranging from 1.5 to 260 ha. A higher diversity of species (199 taxa) was noted along tram-lines at 200 study sites in Warsaw (Sudnik-Wójcikowska, Zarzycka, unpublished data). A lower number of species encountered on the Palace may be attributed to the spatial isolation of the building.

The bryophyte flora of the Palace of Culture tends to be poor in species. The majority of species encountered on the horizontal roof surfaces of the Palace are associated with habitats strongly transformed by man.

Spectrum of life forms

Earlier it has been pointed out that therophytes contributed significantly (40% of the flora) to the flora of the Palace. Similar results were obtained for other polyhemorobic habitats, e.g. along tram-lines in Warsaw – therophytes comprised 45% of the flora, in the immediate vicinity of the Palace – 44%, and in the zone of strongest anthropopressure in Warsaw – 47% of the total number of species. By contrast, the percentage of therophytes decreased to about 33% in the case of Warsaw.

There was also a relatively high frequency of woody species (22%) in the flora of the Palace, whereas their contribution to the flora of Warsaw and immediate surroundings of the Palace was much lower (10%). Similar results were obtained by Jackowiak (1990) for different land utilization types in Poznań. By the sides of tram-lines the seedlings of trees and shrubs comprised 15% of the total number of species.

Most phanerophytes (80%) growing on the horizontal roof surfaces of the Palace were represented by one or several individuals. However in the case of some anemochorous species, the number of seedlings was relatively high in spite of the fact that the diaspores had been introduced from other areas. It is notable that such species as *Populus x euramericana* (a hybrid between *P. nigra* and American *Populus* species, represented by more than 500 individuals), *P. alba* (over 200 individuals) and *Betula pendula* (over 100 individuals) were also frequently encountered. It is interesting that the frequency of woody species did not decrease with increasing height (and decreasing area size).

Brandes (1992) indicated a high frequency of trees and shrubs on city walls in southern and western Europe. He stressed that some specimens reached considerable size and were referred to as "Indikator für fehlende Pflegemassnahmen". The above author reported 135 species from horizontal wall surfaces of ruins in the Harz mountains (Brandes 1996), among which trees and shrubs made up 22% of the flora. Świerkosz (1993) pointed a higher percentage of phanerophytes (25%) on the walls in Wrocław whereas the proportion of therophytes was 19% only.

In the past 40 years the Palace of Culture has been renovated several times. However the underground parts of plants overgrowing the roofs were difficult to remove due to the specific nature of the substratum. In consequence, a high number of seedlings of phanerophytes as well as a fairly low number of juvenile specimens of trees and shrubs were noted.

Spectrum of historical-geographical groups of species

Rostański (1998) indicated that anthropophytes comprised 10-30% of the flora on post-industrial heaps of the Upper Silesia region, whereas their representation was higher in the flora of reclaimed heaps. The above differences in the frequency of species distinguished in the historical-geographical classification resulted from the spatial isolation of the area studied and were determined by the intensity of human impact. In the case of tram-lines where spatial isolation is of less importance the proportion of anthropophytes increased to about 48%. On the other hand, alien species comprised 35% of the flora of the Palace. The aforementioned group of plants was dominated by permanently established species (22%). Among species temporarily introduced (casuals) the contribu-

tion of ergasiophytes was appreciable. The absence of ephemerophytes from the area studied confirms the fact that the Palace is a spatially isolated unit.

Flora and habitat conditions

Celesti Grapow et al. (1993) pointed out that the lack of water in the substrate hampered the establishment and maintenance of species on old Roman walls. In the case of the Palace of Culture the moisture content did not exert a strong selective influence on the flora. This was not only attributable to the differences in the climatic conditions between Rome and Warsaw but to the particular construction of roofs of the Palace as well (see chapter: The Palace of Culture and Science architecture and construction).

The differences in moisture conditions between the areas studied were reflected in the spectrum of moisture indicator values for species recorded from the Palace (Figure F ranged from 2 to 10). It appeared that temperature had a strong selective influence on the flora, which was dominated by species tolerating wide ranges of temperature. Among the 8 most frequently occurring species, the majority are either indifferent to temperature or thermophilous herbaceous plants exhibiting higher demands for light.

Due to the different situation of the surfaces in relation to the highest parts of the building the south-facing roof surfaces of the Palace receive slightly more solar radiation than the north-facing surfaces. Therefore the differences between the flora of roofs exposed to the north and south are less strongly marked.

Location of the surface above the ground does not affect the flora essentially. Vertical climatic differences are slightly marked up to 60 metres of altitude (see chapter "Natural conditions in the vicinity of the Palace of Culture and Science"). The flora of strongly treaded and regularly cleaned terrace (116 m above the ground) is very scanty. However most of the terraces and stairs of the ground floor are not subject to such strong anthropopressure.

Dispersal mechanism

The determination of dispersal strategies of particular species (based on the incidence of seeds and fruit) recorded in the area studied made it possible to follow the sources of those species. The flora of the Palace was dominated by species possessing light diaspores dispersed through the action of wind and strong upward air currents. Fairly numerous seedlings of *Salix* and *Populus* species were even noted on upper floors of the Palace although their seeds remain viable for 3-4 weeks only (Hryniewicz-Sudnik et al. 1987).

In some cases epizoochory and endozoochory were one of the principal methods of dispersal. However the establishment of the majority of species with heavy, fleshy diaspores in the area studied was usually a result of human activities. Epizoochory (birds) and anemochory explain the long-distance translocation of the diaspores of species encountered on the Palace, which were rare or absent from the city centre.

West winds prevail in Warsaw throughout the year (Bogucka 1998). However in spring the importance of east winds blowing from the Vistula 2 kilometres away increases. Air currents moving from above the river can transport diaspores of species of wet habitats such as that of *Populus* and *Salix*, whose seeds ripen in spring.

Anemochorous species also contributed remarkably to the flora of city walls in other regions of Europe (Werner et al. 1989; Wittig 1991; Brandes 1992, 1996). The high frequency of myrmecochorous species among the vegetation of walls

was noteworthy as well (Ulbrich 1939; Wittig 1991; Brandes 1996). It appeared due to the spatial isolation of the Palace (e.g. roof surfaces at least 20 m above the ground) that the dispersal of diaspores by ants and mammals was not possible.

CONCLUSIONS

The relatively high number and fairly low frequency and abundance of most species suggest that the flora of the Palace is very "unstable". Among the most frequently encountered species were natives (65%) which were best adapted to survive in strongly disturbed sites.

The majority of species recorded from the horizontal roof surfaces of the Palace were introduced temporarily. In winter seeds appear to play an important role in allowing the persistence of plants in habitats subjected to unfavourable climatic conditions. It was demonstrated that therophytes prevailed among the wall-dwelling flora of the Palace. Relatively frequent phanerophytes were not regarded as permanent components of the flora since they were mostly represented by juvenile specimens and were incapable of producing seeds. The introduction of tree and shrub seedlings into the area studied was, therefore, determined by the inflow of diaspores from other areas.

From the present study it may be concluded that the most important factors in determining the flora of the Palace were:

- Winds and strong upwards currents. The diaspores of most species were dispersed by wind. On the other hand, the diaspores were more likely to be blown away by the wind. Other methods of dispersal such as anthropochory and zoochory were of less significance to the flora of the Palace.

- Temperature. The flora of the Palace consisted mainly of thermophilous plants or species tolerating wide ranges of temperature conditions (species indifferent to temperature comprised 45% of the total number of species). The differences in the species composition between the north and south facing roof surfaces of the Palace (which were related to the abundance of species) were primarily attributable to the differences in temperature.

- Moisture content. As opposed to other polyhemorobic habitats and city walls, moisture content does not exert a strong selective influence on the flora of the Palace. A relatively high frequency of hygrophilous species was observed.

It seems that other factors such as insolation and the situation of the surface areas (on different floors of the building) were not the major factors in determining the wall-dwelling flora of the Palace. It appears that species diversity is determined by the form of utilization of the area (management practices and intensity of trampling). In spite of the extreme habitat conditions and spatial isolation of the building, the Palace of Culture and Science is not a "floristic desert". However most species inhabiting the roof surfaces of the Palace have been introduced temporarily and occur with a low frequency.

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FLORA NAJWYŻSZEGO BUDYNKU W POLSCE
(PAŁAC KULTURY I NAUKI W WARSZAWIE)

STRESZCZENIE

Badania florystyczne prowadzono na najwyższym w Polsce budynku, którego zewnętrzne poziome powierzchnie mają charakter siedliska polihemerobowego. Na powierzchni liczącej w sumie 16.5 tys. m² stwierdzono łącznie 111 taksonów roślin naczyniowych (65% spośród nich to taksony rodzime) i 6 mszaków. Obok stosunkowo dużego bogactwa gatunkowego i dużej obfitości występowania niektórych gatunków (ponad 1000 osobników: *Chaenarrhinum minus*, *Sagina procumbens* i *Eragrostis minor*), a także dominacji (85%) anemochorów, charakterystyczną cechą flory stanowi znaczny udział roślin termofilnych lub obojętnych na działanie temperatury i stosunkowo duża (jak na ten typ siedliska) liczba gatunków wilgociolubnych. Spektrum form życiowych wykazuje zwiększone udziały terofitów i fanerofitów (odpowiednio 40% i 22% flory). Nie stwierdzono znaczących różnic pomiędzy florą powierzchni rozmieszczonych na różnych kondygnacjach. Natomiast niewielkie, choć zgodne z oczekiwaniami, są różnice między florami terenów położonych po północnej i południowej stronie budynku.

SŁOWA KLUCZOWE: synantropizacja flory, siedliska polihemerobowe, flora murów, flora Warszawy.