Ann. Bot. Fennici 42: 185–193 ISSN 0003-3847
Helsinki 29 June 2005

Floristic differences in some anthropogenic habitats in Warsaw

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Received 2 July 2004, revised version received 24 Sep. 2004, accepted 25 Jan. 2005

Sudnik-Wójcikowska, B. & Galera, H. 2005: Floristic differences in some anthropogenic habitats in Warsaw. — *Ann. Bot. Fennici* 42: 185–193.

Floristic studies of four different habitats in Warsaw were carried out: two habitats strongly transformed by man (tramlines and the exterior horizontal surfaces of the highest building in the city, the Palace of Culture and Science), and two green areas (cemeteries and botanical gardens). A floristic list, which included only the spontaneous vascular flora, was compiled for each habitat. The aim of the study was to analyse the differences between the floras of the four habitats. The richness and composition of the flora were investigated with respect to the historical-geographical groups of species, the spectrum of life forms, and the mode of plant dispersal. The richness of the flora of cemeteries and botanical gardens reflected the particular land use of those habitats. There was a higher incidence of therophytes in the strongly transformed habitats (tramlines, Palace). A high incidence of tree seedlings (mostly species producing light seeds) and anemochorous species was observed in the flora of the Palace.

Key words: composition of flora, synanthropic flora, anthropogenic habitats, urban flora

Introduction

Floristic studies have been carried out in towns and on various anthropogenic habitats in Europe over a long period of time. A number of papers dealing with this problem especially in central Europe have been compiled, e.g. by Gilbert (1987), Wittig (1991, 2002), and Sudnik-Wójcikowska (1998).

In Poland, intensive studies of urban flora have been conducted since the 1970s. Complete floristic lists from many towns (e.g. Szczecin, Opole, Kraków, Gdańsk, Kielce, Słupsk, Bielsko Biała, Bełchatów, Tychy) are available. In the 1980s and 1990s distribution maps of plant species for more than ten cities were published (e.g. Warszawa, Poznań, Łódź, Jaworzno). The flora of strongly transformed habitats, e.g. railway areas, sea ports, river harbours, post-industrial heaps, rubble heaps, and industrial land, was investigated. Most authors determined only the floras of these habitats. It was difficult to compare the results of these studies because different research methods were used.

Detailed floristic studies were carried out in Warsaw over a period of 20 years (Sudnik-Wójcikowska 1987a, 1998a). The changes in the flora in the past 150 years as well as the relation-

ship between the flora and the impact of man's activities (anthropopressure), e.g. the effect of urban heat island, were analysed (Sudnik-Wójcikowska 1987b, 1988, 1992, 1998b, 2000, Sudnik-Wójcikowska & Moraczewski 1993). In the past few years specific urban habitats distinguished within the city limits were studied extensively. The present study analyses the flora of two types of habitats strongly transformed by man: tramlines and crevices of the exterior horizontal surfaces of the highest building in Warsaw and the flora of two types of urban green habitat: cemeteries and botanical gardens. We applied different methods of floristic sampling, due to the distinct and specific character of each of the habitats studied.

The aim of the present study was to determine the composition of the flora in the four habitats and to analyse the differences between them.

Materials and methods

Specific character of the habitats studied and the method of data collection

Various habitats distinguished within the city are characterized by disturbed water, soil and local climatic conditions, and by increased levels of air pollution, all of which result from strong urbanization pressure.

Warsaw covers an area of 430 km^2 and has a population of two million. As in other cities of Europe, the historic and commercial centre is characterized by dense housing while the suburbs contain many green areas. The habitats analysed in the present study are, however, subject to different anthropopressures. In addition, they cover different surface areas and are accessible to plants to various degrees.

Field research was restricted to areas of homogenous land use, and was aimed at obtaining complete floristic lists. We took into account only plants spontaneously self-perpetuating outside their plots without control (especially in botanical gardens and cemeteries). A comparative analysis of the floral composition of the habitats was also undertaken.

Tramlines

Tramlines are strongly transformed, anthropogenic habitats, subject to extremely harsh conditions, and are not easily penetrated by plants. In man-made embankments, the structure of soil is disturbed since the sub-soil has been filled with concrete, asphalt, or coarse or fine gravel. The plants are threatened by mechanical damage. The amount of solar radiation combined with an almost total lack of shade, great temperature contrasts, and loss of humidity in the porous ground layers, create on hot days conditions similar to those of a desert. Tramlines are usually located in the immediate vicinity of busy streets and roads where car traffic is the most important source of pollution. Herbicides and oxidant weed killers, applied twice a year (in spring and late summer), destroy the plants growing along the tramlines.

The Warsaw tramline network (Fig. 1) is approximately 200-km long and the track area is 5–6 metres wide (a total surface of 1.1 km^2). Field studies revealed that the sites investigated were covered with plants only to a small degree (plant communities developed best near the tram stops). We, therefore, chose 123 sampling areas with a minimum of 20% plant coverage (along the sides of the tramlines) for the study. In the years 1995–1996 we made phytosociological relevés in these sampling areas: 117 relevés were recorded in spring and early summer (before the first chemical spraying) and 120 relevés in late summer and autumn (after the second chemical spraying). In 2001 we investigated several dozen 50–100-metre-long sections of tramlines in order to supplement the list of species recorded in the research area, and we made an additional 61 relevés.

We obtained quantitative and qualitative data from phytosociological relevés to determine the indicative value of plants occurring along the tramlines (Sudnik-Wójcikowska 2000) as well as the changes in the composition of species during the growing season. Based on field observations and 298 relevés we analysed the floristic list (B. Sudnik-Wójcikowska, H. Galera & E. Zarzycka unpubl. data).

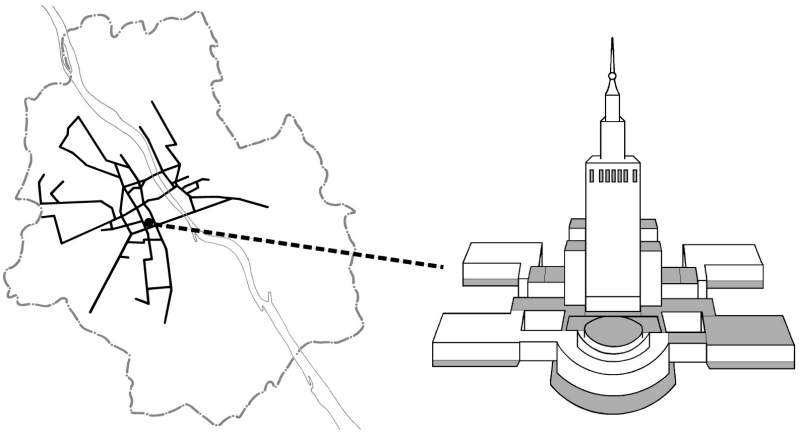

Fig. 1. Tramline network studied in Warsaw and the location and construction of the Palace of Culture and Science (in grey: areas sampled in the Palace).

External horizontal surfaces of the highest building in Warsaw

The Palace of Culture and Science, 231 metres high, is the tallest building in Warsaw. It is unique in the scale of the city. It was built in the early 1950s in the very centre of Warsaw, in the part of the city mostly destroyed during the Second World War (Fig. 1). The architecture of the Palace, which was 'a gift' from the former Soviet government, is complex (it is a group of structures different in size and height). The particular construction and the poor condition of the Palace today encourages the growth of plants on the external horizontal surfaces of the building (crevices of walls, roofs, terraces and stairs). The plants exist under unfavourable soil and local climatic conditions (strong air currents, considerable fluctuations in temperature conditions and precipitation determine the water supply, and only thin layers of soil are available to the plants). The various management practices, carried out every 2–3 years, including mechanical removal of plants and the use of weed-killers, also contribute to the poor development of plants. Trampling and increasing soil salinity play a less significant role in limiting the growth of plants and their effects are noticeable only in some places (stairs and terraces at the base of the building). The lower concentration of traffic pollutants is ascribed to the height and spatial isolation of the building. Our survey was carried out in 1996 during the growing season. Altogether 24 sampling areas were chosen based on the degree of plant cover (the coverage of a stand higher than 1%). The sites sampled cover an area of 16 500 m^2 and were situated 0–116 m above ground level.

We compiled a list of species for each sampled area and we distinguished some groups of plants (trees and shrubs, hygrophilous and most abundant species). A separate study was conducted to determine the effect of exposure on the species composition. In addition we analysed the role of species tolerating different ranges of light, temperature and humidity conditions in the flora of the Palace (Galera & Sudnik-Wójcikowska 2000a, 2000b). In the present work we took into consideration the total flora of all the sampled sites.

Cemeteries

Most of the cemeteries in Warsaw are planted with trees and are highly shaded. They are also subject to long-lasting anthropopressure, which results in the alteration of soils and lowering of the ground water table. The changes in the plant cover are associated with intensive management practices (e.g. conservation of old cemeteries, planting of trees along alleys). A great number of taxa, of which only some are capable of spreading spontaneously, are introduced to cemeteries as decorative plants (e.g. through the planting of ornamentals, and by bunches of flowers and wreaths being placed on the graves).

The cemeteries in Warsaw vary in age (the oldest cemetery dates from 1790, the most recent

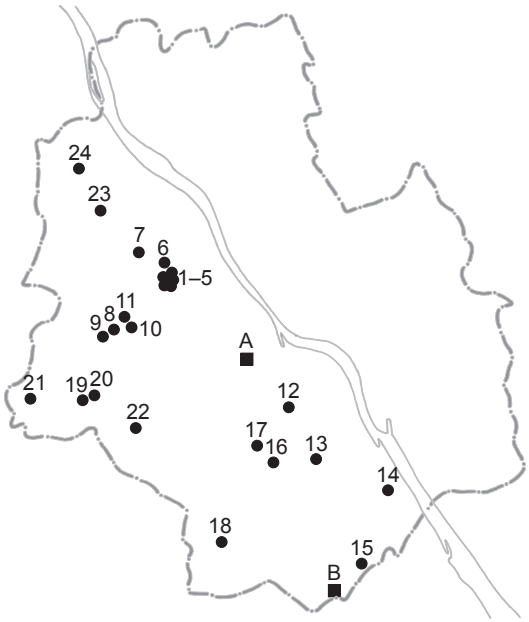

Fig. 2. Location of the botanical gardens (A: Botanical Garden of Warsaw University, B: Botanical Garden, Center for Biological Diversity Conservation of Polish Academy of Science) and cemeteries (1–24) on the left side of the Vistula River.

was established in 1972) and in size. Moreover they are situated in different parts of the city. We investigated 24 cemeteries situated on the left side of the Vistula River (a total area of 2.83 km^2, Fig. 2) in the years 1989–1991. The results of studies on the spatial variability of flora in cemeteries, with regard to various habitat conditions, were presented by Galera *et al*. (1993) and Lisowska *et al*. (1994). We analysed the total list of plants occurring spontaneously in the cemeteries.

Botanical gardens

Botanical gardens are areas of intensive cultivation of numerous plant species, varieties and hybrids. The combination of taxa cultivated in the gardens changes every year. Moreover the plants are introduced from various sources. Botanical gardens are internally differentiated habitats, a feature which is attributed to the various forms of utilization of the land. In addition to areas, subject to direct anthropogenic influence (e.g. intensively cultivated flower beds, heavily trampled roadsides), there are areas which have been only slightly transformed by man (e.g. parkland areas).

There are two botanical gardens in Warsaw: the Botanical Garden of Warsaw University set up in 1818 and covering an area of 0.05 km^2, and the Botanical Garden, Center for Biological Diversity Conservation (Polish Academy of Science) established in 1974 with an area of 0.40 km^2 (Fig. 2). A complete list of spontaneously occurring taxa recorded in the botanical gardens in Poland was published by Galera (2003). The internal variability of the flora within the particular botanical gardens is discussed in a separate paper (Galera & Sudnik-Wójcikowska 2004).

Analyses of the flora

The flora of the four types of habitats studied were compared with respect to:

— the richness of species;
— the percentage of synanthropes, including native species (apophytes), permanently established alien species (species which arrived before the 15th century, called archaeophytes, and those that arrived after the 15th century, called kenophytes) and garden escapes (ergasiophygophytes); the classification was introduced by Thellung (1915) and supplemented by Kornaś (1982);
— the percentage of life forms (Raunkiaer 1934), mainly annuals (therophytes), trees and shrubs (phanerophytes);
— the percentage of anemochores (species producing diaspores which are dispersed by wind).

Results

Species richness

The flora of the habitats studied differed in the number of taxa. The flora of urban green areas (cemeteries and botanical gardens) supported a high number of taxa (Fig. 3). The botanical gardens were characterized by the highest diversity of spontaneous flora (weeds and escapes from

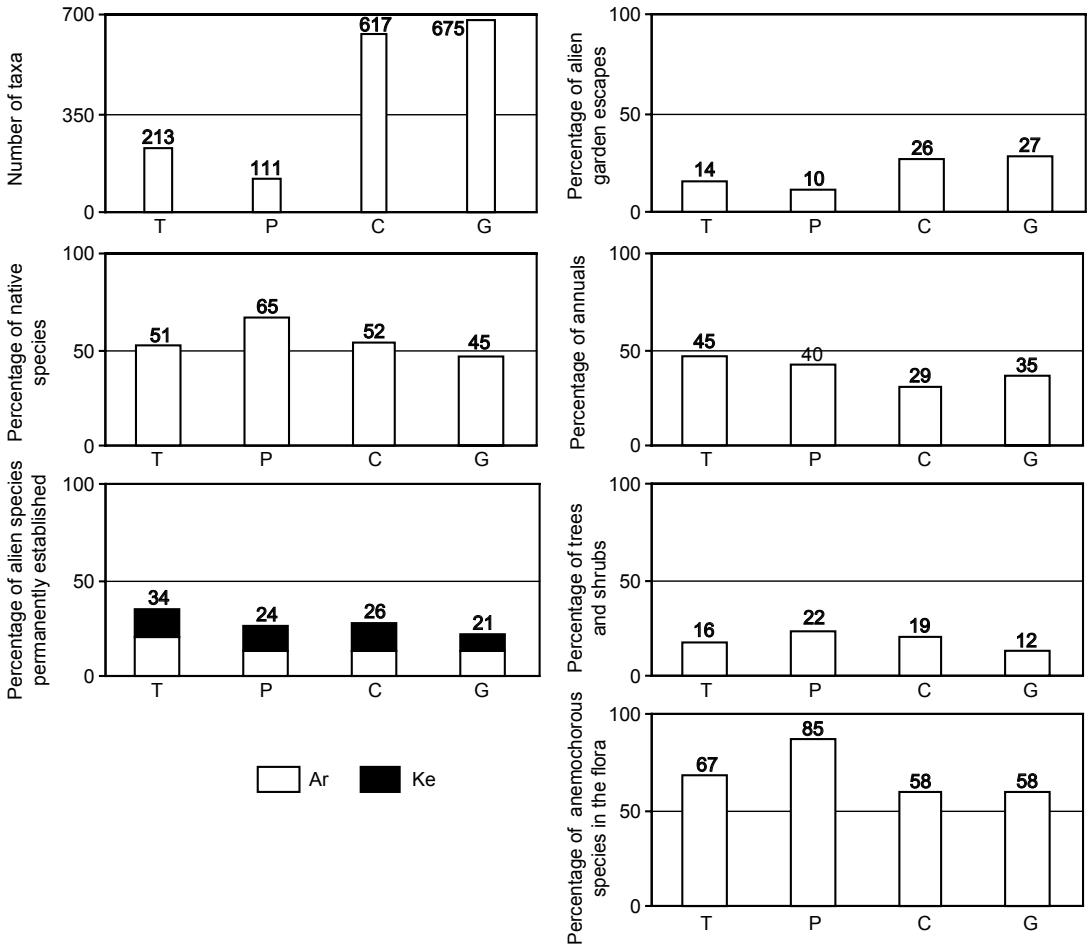

Fig. 3. Richness and composition of the flora (percentage of particular species groups) of the four types of habitats studied in Warsaw. T: tramlines, P: Palace of Culture and Science, C: cemeteries, G: botanical gardens. Abbreviations: Ar: archaeophytes, Ke: kenophytes.

cultivation) in relation to the area the gardens occupied; an area of 0.45 km^2 yielded 646 species and 29 cultivars. In the cemeteries (total area of 2.83 km^2) 585 species and 32 cultivars occurred spontaneously. These figures are high when compared with those obtained for the flora of Warsaw (Sudnik-Wójcikowska 1987a, 1998a) from a much larger area (945 synanthropic species, an area of 430 km^2).

The flora of strongly transformed habitats was poor in species. The lowest number of species (about 100) was noted in the Palace of Culture and Science. The flora of tramlines was composed of some 200 species, but the area we investigated was several times bigger. As opposed to the Palace of Culture and Science, the sides of the tramlines are much more easily penetrated by seeds and fruit (compare also the proportion of anemochorous species, Fig. 3). In both habitats the plant cover is destroyed deliberately. However, the plants growing along tramlines are destroyed much more frequently and by various chemical compounds.

Historical-geographical groups of species

The great richness of taxa in the flora of cemeteries and botanical gardens is determined mainly by the high diversity of alien taxa escaping from cultivation (ergasiophygophytes, over 25%, Fig. 3),

which have not become permanently established in their habitats. The proportion of these plants in the flora of tramlines and the Palace of Culture is 2–3 times lower. On the other hand ephemerophytes (alien species introduced temporarily but not escaping from cultivation) comprise less than 2% of the flora in all the habitats studied.

The flora of the Palace of Culture and Science is represented mainly by native synanthropes, whereas that of tramlines is relatively rich in permanently established alien species (Fig. 3), especially archaeophytes, which account for 19% of the flora (about 10% in the case of the other habitats we investigated: the Palace of Culture and Science 11%, cemeteries and botanical gardens 12%, respectively).

It is interesting to note that the proportion of kenophytes ("newcomers") is similar in all the habitats studied. They comprised 9%–15% of the flora. The three most abundant species occurring in the flora of the Palace are: *Eragrostis minor*, *Chaenorhinum minus*, and *Sagina procumbens*; the latter two species are native to the flora of Poland. In the tramlines all the three dominating species were identified as kenophytes (*Eragrostis minor*, *Amaranthus retroflexus*, *Atriplex tatarica*; Sudnik-Wójcikowska 2000). The high incidence of *Eragrostis minor* in the flora of the above habitats is noteworthy.

Spectrum of life forms

The spectrum of life forms in the habitats investigated is also interesting. The contribution of annuals (Fig. 3) to the flora of tramlines and the Palace of Culture and Science is appreciable (45% and 40%, respectively; they comprise about 42% of the entire flora of Warsaw; Sudnik-Wójcikowska 1987a, 1998a). These transformed habitats are unstable and the prevailing conditions do not favour the growth of plants, especially perennials. The proportion of the latter in the flora of the above habitats does not exceed 40%, whereas in the case of cemeteries and botanical gardens they make up more than 50% of the flora.

In view of what has just been said, the high percentage of phanerophytes (trees and shrubs, 22%) in the flora of the exterior horizontal surfaces of the Palace of Culture and Science is remarkable (Fig. 3; compare the percentage of phanerophytes in the flora of the city, 12%). It should be emphasized that under these severe conditions the species were represented by juvenile specimens only (mainly seedlings). Many of the tree species produce light seeds, especially poplars (*Populus*) and willows (*Salix*), whose diaspores could have been dispersed through the action of wind (anemochory) or, infrequently, by birds (epizoochory), and introduced from the riverbanks of the Vistula (1–2 km from the Palace). The plants were subject to strong environmental stress. However, the interspecific competition between plants was low. A great number of seeds germinated, but young specimens were not able to persist through the winter.

Trees and shrubs play an important role in the flora of cemeteries in Warsaw (19% of the flora, Fig. 3). The trees and shrubs planted along the alleys and near the graves are the main seed sources. The same holds true for botanical gardens, but the young specimens of phanerophytes are usually eliminated due to regular weed control.

Dispersal strategies

Most of the species we recorded in the habitats studied were dispersed by wind (Fig. 3). Anemochorous species comprised 85% of the flora on the highest-situated external horizontal surfaces of the Palace. In the tramlines the incidence of anemochorous species was lower (67%), the diaspores being transported due to the strong motion of air as a result of the traffic flow in the street. In the other habitats the incidence of anemochores did not exceed 60%.

Discussion

The form of land utilization has a great impact on the species diversity of a given area. The influence of land use on the plant cover has been analysed frequently and in different aspects. Data obtained from different European cities indicate that the various biotopes distinguished in urban areas reflect different types of land use (Wittig 2002). Breuste (1994) emphasized that a given type of land use is not a stable condition but a

process. The author points to the complexity of the process and the significant role of other factors in determining the urban habitat conditions such as the composition and moisture of the substratum, topography, climate or plant cover. Sukopp (1990) and Breuste (1994) suggest that the current land use is usually the leading factor in determining the urban flora, which interacts with other features of the habitat (*Hegemonie der gegenwärtigen Flächennutzung*).

Anthropopressure and biological diversity

The results of the present study confirm that anthropopressure is a complex of factors, which either have an impoverishing or enrichening effect on the flora. The various horticultural practices carried out in botanical gardens and cemeteries result in a greater richness of taxa (cultivated plants are an immediate source of diaspores). On the other hand, weeding (especially in botanical gardens) eliminates unwanted plants in the early stages of their development. This mainly applies to trees and leads to a reduction in their occurence.

The development of plant cover of tramlines as well as that of roofs and terraces of the Palace is restricted due to extreme conditions pertaining in those habitats. In the case of tramlines the diaspores have easy access to possible germination places. However, the spatial isolation of the Palace of Culture and Science impedes the influx of heavier diaspores to the higher horizontal surfaces of the building. Thus species (especially phanerophytes) producing light diaspores have a clear advantage over other species.

Comparative analysis of the flora of the habitats considered in the study and analogous habitats in other cities

The Palace of Culture and Science in Warsaw is a unique mid-20th century skyscraper and it is difficult to locate a similar type of construction elsewhere in order to compare habitats, although papers dealing with the flora of walls were published in Europe in the 19th century (e.g. Caspary 1860). German authors (e.g. Sukopp 1986, Wittig *et al*. 1993, Wittig 2002) clearly distinguished habitats on old walls and historical monuments from those on modern buildings. They pointed out that the latter habitats were characterized by extreme conditions and were poorer in species. These results are in agreement with those obtained for Warsaw.

A number of papers, which concern the plant cover of city walls (e.g. Weretelnik 1982, Darius & Drepper 1984, Gödde 1987, Ceynowa-Giełdoń 1988, Werner *et al*. 1989, Brandes 1992, 1996, 1997, Celesti Grapow *et al*. 2001, Caneva *et al*. 2003, Celesti Grapow & Blasi 2003) have been published. However, they deal mainly with the vertical stone and brick walls of buildings dating from the 19th century or earlier. Old walls, which are usually quite low, are easily penetrated by diaspores. The flora could even have developed hundreds of years. The above-mentioned authors confirmed that old walls supported a high number of species, especially in the south of Europe (e.g. 334 species recorded in the archaeological area of the Caracalla Baths in Rome; Celesti Grapow & Blasi 2003). In addition they indicated a high incidence of native species, well adapted to high and extremely high temperatures (e.g. aliens comprised only 10% of the flora). Therefore the high proportion of native species in the flora of the Palace of Culture and Science (65%) was striking. However, they were represented mainly by species with a wide ecological amplitude (and rarely by thermophilous species). These species do not show preference for warm habitats but simply tolerate them. Similar findings pointing to a high incidence of native species in the flora of city walls were obtained for Tallin in northern Europe (Brandes 1997).

Although a great number of papers have dealt with urban transportation corridors, little attention has been paid to the flora of tramlines. Brandes (1997) indicated that *Bunias orientalis* spread along the sides of the tram network in cities of Estonia. The habitats of overhead metro rail (Kowarik 1986) could be regarded as similar to those of tramlines.

Among numerous papers on the plant cover of cemeteries in cities (e.g. Cox 1977, Pyšek 1985, 1987, Zisenis 1996) special attention should be paid to the works of Graf (1986) and Schmitz

(2000), which dealt with the cemeteries in Berlin. The flora of cemeteries in Warsaw is similar to that of the Berlin cemeteries as regards the spectrum of life forms (e.g. therophytes 30%, phanerophytes 14%). In addition, the flora of cemeteries in Warsaw and Berlin is similar as regards the historical-geographical groups of species (e.g. apophytes about 50%, archaeophytes 15%). So it can be seen that identical forms of land use lead to a relatively uniform composition of the flora within the same climatic zone.

The results obtained for the flora of botanical gardens in Warsaw are in agreement with those of other botanical gardens in Poland (located in seven cities; Galera & Sudnik-Wójcikowska 2004). Studies carried out in other cities of Europe (e.g. Koževnikov 1935, Evtjuchova 1949, Graf & Rohner 1984, Abner & Laansoo 2001) revealed that the richness of taxa recorded in botanical gardens was determined by the form of land utilization. However, the different methods of research applied in the above studies make it impossible to compare the results directly.

Acknowledgement

The authors thank Dr. J. Parker for improving the English.

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