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THE SYNANTHROPISATION OF VASCULAR PLANT FLORA OF MIRES IN THE COASTAL ZONE (KASHUBIAN COASTAL REGION, N POLAND) – RANGE, REASONS FOR, AND SPATIAL CHARACTERISTICS

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CONTENTS

ABSTRACT

Agnieszka Budyś. *The synanthropisation of vascular plant flora of mires in the coastal zone* (*Kashubian Coastal Region, N Poland*) *– range, reasons for, and spatial characteristics*. Monogr. Bot., Vol. 98, 55 pp., 2008.

The paper deals with symptoms, directions and actual state of anthropic transformation of the flora in various ecological types of peatlands in the coastal zone. The main purpose of the work was to define phases and characteristic features of flora's change in particular mires types and point the reasons for this process. The research was conducted in eastern part of Polish Baltic Coast (Kashubian Coastal Region). Contemporary flora was recorded in 2000-2004. The floristic list was completed with all data from former research. Chosen features of environment were analysed using topographic and geological maps and aerial photographs. Correlation between flora differentiation and some features of environment were analysed with multivariate analyses (DCA, PCA, RDA, CA) and GIS technique. There were 958 species recorded in the total flora of studied area, 93 among them became locally extinct. The big share in contemporary flora have synanthropic species and plants of wide ecological amplitude. Geographically alien species stand for 24% of nowadays flora. The results show that due to anthropic pressure, coastal raised bogs and fens are presently a mosaic of secondary habitats with very high floristic diversity, however raised bog habitats are more resistant to alien species expansion than fens. Despite deep flora disturbances, such as eurytopisation or allochtonisation, contemporary flora of coastal peatlands still has some characteristic features connected with geology, ecological differentiation and geobotanical location.

Key words: vascular plants, peatlands, raised bog, fen, anthropic pressure, species recession, floristic richness, GIS, multivariate analysis, Poland

1. INTRODUCTION

Flora transformation, caused by human activity, is an element of changes of the plant cover, described as synanthropisation. The core of this process is replacement of natural systems by secondary ones formed by cosmopolitan, allochtonic and eurytopic components. Synanthropisation of the flora consists of e.g. expansion of hemerophilous species, retreat of hemerophobic species, apophytism and neophytism. This processes lead to deprivation of such flora and plant communities features, which have been predefined by the history of regional flora and climate (Faliński 1966, 1972, 1998, 2000; Sukopp 1972; Kornaś 1981; Olaczek 1982; Jackowiak 1998; Sudnik-Wójcikowska 1998). The main reason for contemporary transformations of flora is anthropogenic changes to the environment (e.g. Kornaś 1972, 1981).

Peatbogs are ecosystems that are considered particularly susceptible to any disturbance of abiotic conditions. Drainage works are usually the first stage of human activity at peatbogs and set the conditions for their further exploitation: peat excavation, agriculture or forestry (Ingram 1992). Decrease of the groundwater level leads to breaking the anaerobic process of peat formation and begins the process of decay. As the effect soil structure changes, water capacity and permeability decreases (Okruszko 1993), and in consequence – the subsidence and the decession of the peatbog deposit starts (Jasnowski & Ilnicki 1988).

The consequence of changing abiotic conditions are significant and usually irreversible changes in the plant cover of peatbogs (e.g. Görs 1969; Tallis 1983; Jasnowski & Ilnicki 1988; Cross 1992). The high sensitivity of peatbog flora to changes in environmental factors is connected to relatively narrow ecological amplitude of the mire species. Peatbog plants are adapted to specific features of this habitat, such as: generally high water level that varies within the vegetation season; oxygen deficit; deficit of assimilable nitrogen, phosphorus and potassium; and high daily changes of temperatures at the ground surface (Dierssen 1992). The highest level of specialisation is represented by raised bog species, which occur in extremely acid and poor in nutrients habitats. In general, peatbog species are recognised as stenotopic organisms: higro- and hydrophytes, light-dependent and oligothermic plants (Jasnowski 1975; Herbich & Herbichowa 2002).

Habitats and plant cover of mires in Poland, as in the rest of Europe, are contemporary greatly disturbed by anthropogenic pressure. It is estimated that in Poland more than 80% of surface covered by these ecosystems are affected by human activity (Jasnowski 1972; Lipka 1984). Meadows and pastures dominate disturbed fens, and now cover ca 73% of their original surface. More than 50% of the area of raised bogs is covered by forest communities, which have developed spontaneously with the decrease of the groundwater level, or have been planted (Jasnowski *et al*. 1968; Jasnowski 1972; Lipka 1984). A comparison of the historic diversity and composition of peat-forming phytocoenoses with the contemporary vegetation showed that two main processes overlap in the transformation of peatbogs: the disappearance of localities of mire species and the development of secondary vegetation (Görs 1969; Dierssen 1982). The only available preliminary synthesis of changes in plant cover of peatbogs in Poland (Jasnowski 1972) showed that more than a half of the original area of peatbogs in the northern Poland is now covered by non-peatforming vegetation. This study proved that as the effect of the disappearance of suitable habitats, the localities of mire species have been lost. This process of retreat concerns rare species as well as those which were common in the past. Similar conclusions come out of local studies on flora of peatbogs (Herbichowa 1976; Olesiński & Olkowski 1976; Polakowski 1976). Data compiled by Jasnowska & Jasnowski (1977) showed that more than a half of the vascular plant species in the flora of peatbogs were in danger of extinction. Among mire plants retreating at the European scale there are taxa considered as relics and species that reach the borders of their range in European countries, e.g. *Betula humilis*, *Salix myrtilloides*, *Saxifraga hirculus*. In such cases, losing certain locations might result in the reduction of geographical range of species.

In comparison with the knowledge on the regression of peatbog flora, the process of its enrichment with ecologically and geographically alien species is poorly recognised. A typical feature of pristine mire ecosystems, especially raised bogs and transitional mires, is low diversity of their flora. In Poland the number of taxa in the natural vascular plant flora of mires is estimated at 130-230 species (see Tołpa *et al*. 1967; Jasnowski 1972). Anthropic pressure has enormously increased the number of species in the contemporary flora of peatbogs (Jasnowski *et al*. 1968; Jasnowski 1972, 1975; Dierssen 1992; Aaby 1994). Data collected by Jasnowski (1972) showed that the strongest expansion on peatbog habitats was shown by *Poaceae* and *Asteraceae* families. Among plants of foreign origin, the tendency to inhabit peatlands was demonstrated by 5 species of kenophytes. More recent studies prove that strongly transformed habitats are occupied not only by kenophytes but also by some archaeophytes and diaphytes (Celka & Szkudlarz 2000).

Despite the commonly observed process of anthropogenic changes in the flora of peatbogs, comprehensive studies on this issue based on current data are lacking. Besides identification of quantitative and qualitative changes in the flora of peatbogs, it is important to determine more accurately than has yet been done, what is the relation between the direction of the transformation of flora and the range of habitat changes. Such an analysis would allow us to draw conclusions about the detailed reasons for the changes in flora and would also explain the sensitivity of particular species to disturbance.

Because of numerous threats to the persistence of mires, their significance for the functioning of the natural environment and their scientific value, the problems relating to their efficient conservation are of crucial importance at present (e.g. Tobolski 2003). This is expressed in action programs at national and international levels, such as the Habitats Directive or the European Ecological Network Natura 2000 (Council Directive 92/43/EEC). Determination of the stage of transformation of flora, and drawing conclusions considering the reasons for this process would be a starting point for the prognoses for further changes in the vegetation of peatbogs, and at the same time would provide the basis for proper planning of conservation measures.

The main aim of this study was to recognise the range of anthropogenic changes of flora in ecologically diverse mires in the Polish coastal zone, and to define the spatial aspects as well as the reasons for this process.

This aim was achieved by completing the following research targets:

- comparison of historical and contemporary flora of chosen mires, representative of the Polish coastal zone,
- identification of symptoms, stages and the specific features of the transformation of flora in disturbed peatbog habitats,

- identification of dynamic tendencies among the selected components of flora,
- defining the main stages of anthropogenic changes in the environment of the study area,
- determination of relations between the quantitative, qualitative and spatial variability of flora and the forms of anthropic pressure as well as the identification of the most important factors that influence the structure of contemporary flora of transformed peatbog habitats.

There was a hypothesis formulated that the extent and symptoms of flora synanthropisation in peatlands depend both on the form of human pressure and ecological type of mire.

For this study the fragment of lowlands, which extends between spits and moraine hills along the whole coastline of the Baltic Sea (Kondracki 2001) was selected. This area consists of a complex of fens that predominate the area, and three raised bogs of the Baltic type. In terms of geomorphologic conditions, climate features and typological diversity of these peatbogs, the selected fragment of Kashubian Coastal Region is representative of the eastern section of the coast. Because of the long-term, direct and indirect human pressure, this area at present is a unique mosaic of habitats, diverse in respect of the stage of transformation and the way of land use. This area is distinguishable from other similar complexes by its relatively rich, although not complete, floristic documentation, originating from the 19th and 20th century.

2. STUDY AREA

2.1. Location and borders

According to the regional classification by Augustowski (1969, 1974) used in this study, the studied area is located within the Kashubian Coastal Region and consists of the Błota Przymorskie Plain and northern part of Płutnica Valley. The Błota Przymorskie Plain is a low-lying land about 21.5 km long, and from 1 km to 4.2 km wide, extending alongside the seacoast between the belt of coastal dunes and the edge of the moraine heights. In the eastern part it is divided by Ostrowo Moraine into the Czarna Wda Valley and the Bielawskie Błoto raised bog. The Płutnica Valley is conected to the Błota Przymorskie Plain in its eastern-south part. The total coverage of the studied area is 74.2 km^2 (Fig. 1).

The border of the study area is natural along almost the whole length and generally follows the border between peatbog habitats and the sand or sand-clay formations that occur in the surroundings (Fig. 2).

2.2. Climate

The area of the Kashubian Coastal Region, included by Kwiecień & Taranowska (1974) in the Climatic Region of the Open Sea, remains under the clear influence of the Baltic Sea. The climate of this area is distinguished by warmer winters and cooler summer months than inland, later spring and longer autumn, relatively high annual total rainfall

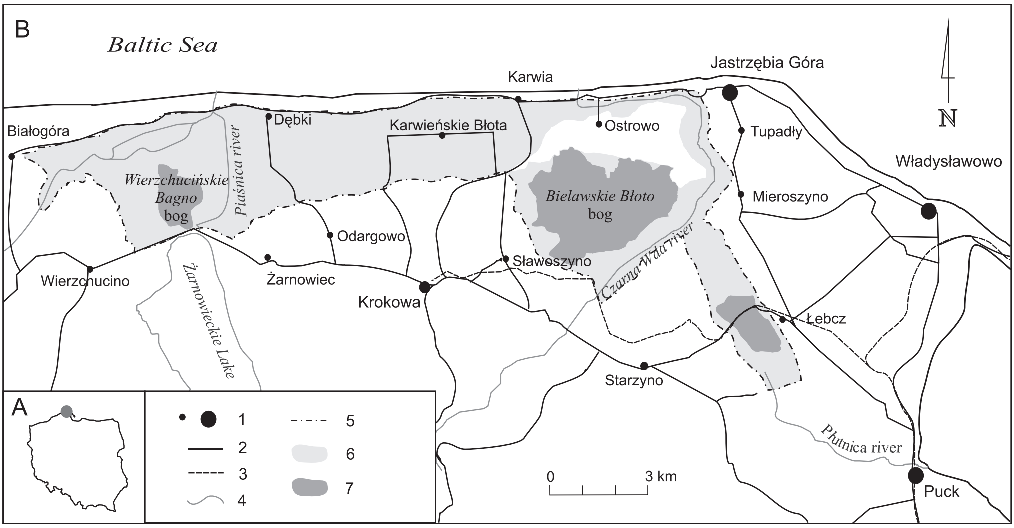


Fig. 1. Localisation and habitat differentiation of studied area
A – general localisation; B – studied area boundaries and topography of surroundings;
1 – human settlements; 2 – main and local roads; 3 – railway; 4 – rivers; 5 – boundary of studied area; 6 – habitat of fen; 6 – habitat of raised bog and transitional mire

(550-700 mm) and high air humidity (annual average 8.3%). In this area the mean ambient temperature of January is -1.4°C, but in July it is 13.8°C (Gerstmannowa 1978-1981). This area is distinguished by frequent mists and high wind speeds (Augustowski 1969).

2.3. Geomorphology and land relief

The land relief of the Kashubian Coastal Region was formed in the Quaternary by glaciers and fluvioglacial water activity (Augustowski 1969). The typical landscape of this area is formed by morainal plateau and marginal stream valleys (Fig. 2). Another feature typical of this region is presence of sandy spits formed by sea accumulation and aeolic activity.

The Błota Przymorskie Plain and Płutnica Valley are filled mainly by Holocene formations: peat, silty sands, and silts of river-floors or of non-drained depressions (Detailed geological map... 1978, 1985, 2002).

The studied area is a flat lowland, located at an altitude of ca 0.3-5 m a.s.l., of rather monotonous land relief.

2.4. Geological and soil diversity

The diversity of the soils in Kashubian Coastal Region is closely associated with its geomorphology: at highlands brown soils occur, formed of clay, loam and clayey sands, and podsols, formed of mound, zandr and river sands. Marginal stream valleys are filled mainly with hydrogenic soils, formed of peat and moorsh (Witek *et al.* 1974).

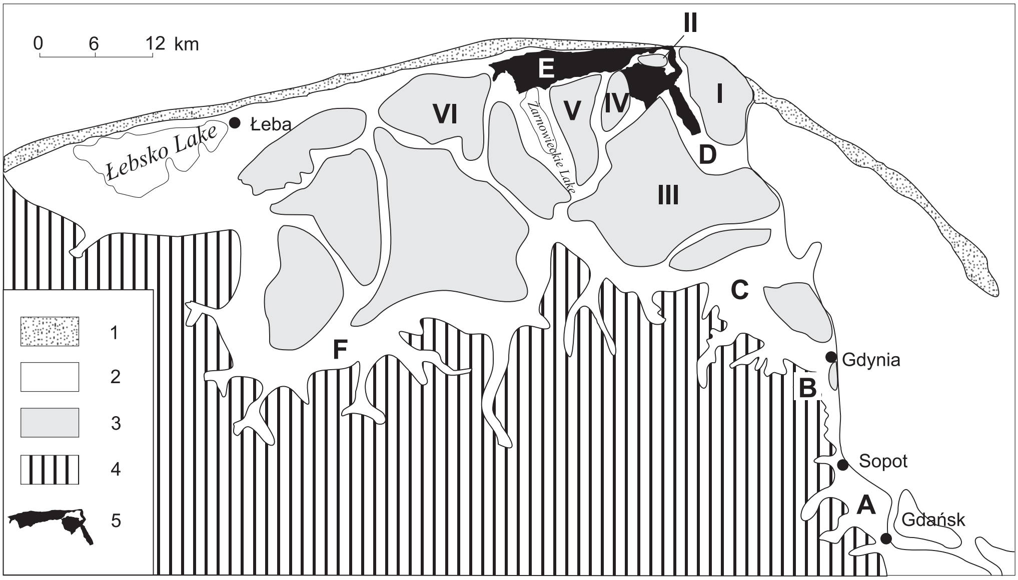


Fig. 2. Localisation of studied area against the background of geomorphology of Kashubian Coastal Region (after AUGUSTOWSKI 1969, changed)
1 – sand-bar; 2 – marginal stream valleys, valleys, troughs: A – Oliwa-Sopot Terrace; B – Redłowo Downland; C – Kashubian Meander; D – Płutnica Valley; E – Błota Przymorskie Plain; F – Reda-Łeba Marginal Stream Valley; 3 – morainal plateau of Kashubian Coastal Region: I – Swarzewo Moraine; II – Ostrowo Moraine; III – Puck Moraine; IV – Sławoszyno Moraine; V – Żarnowiec Moraine; VI – Osieki Moraine; 4 – Kashubian Lakeland; 5 – studied area

Fens prevail on the studied area. The deepest peat deposits (7 m thick), were formed in the valley of the Piaśnica river (SZAFRANÓWNA 1926). Three deposits of raised bogs were located in the study area: Bielawskie Błoto, Wierzchucińskie Bagno and the Łebcz raised bog.

Where unfavourable changes of hydrological conditions occurred, peat soils were transformed into peat-moorsh, moorsh-mineral, or mucky soils (Soil-agricultural map 1973), and locally a complete decession of peat and exposure of the mineral substratum took place.

2.5. Hydrologic conditions

The largest river of the studied area is the Piaśnica, which is the only natural outflow of Żarnowieckie Lake. Water regime in the Piaśnica river basin were strongly transformed in the 60's of the 20th century by the digging out the so-called Channel of the Old Piaśnica, the regulation of the river outlet and the building of the pump station, which led to the disappearance of the one of the two beds of the Piaśnica river, formerly of equal importance. One of the largest lakes within the study area was Ostrowskie Lake, which was located in the lower part of the Czarna Wda Valley, but it was drained in 1950s (Aerial photographs 1947, 1958). A few small lakes and astatic water bodies remain in the study area, such as in the region of Bielawskie Błoto bog. The typical feature of the hydrographical network in the Błota Przymorskie Plain and Płutnica Valley is its strong transformation by human activity, which consisted of regulation and embankments of rivers and the creation of an artificial drainage system (Narwojsz 2000).

2.6. Brief history of settlements and land use

The Błota Przymorskie Plain was inhabited in the middle ages. Villages were built at its mineral and organic edges, as e.g. Karwia and Dębki, which were documented for the first time in the 13th century. Agricultural use of fragments of wetlands was possible only in the end of the 16th century, when Dutch settlers started building the drainage system at Karwieńskie Wetlands. They built settlements of a typical two-row arrangement on the peaty substratum (Biernat *et al*. 2000). The first signs of peat exploitation are visible in maps from the second half of the 19th century, however it might be assumed that peat extraction in this area had taken place earlier (Topographic map 1889). Rapid development of sea-side villages, stimulated by tourism, was observed between the two world wars. After the Second World War, a gradual intensification occurred in farming and forestry. Until the end of 1970s the industrial exploitation of the largest raised bog deposit in the studied area, at Bielawskie Błoto, was started (Machnikowski *et al*. 1985). During the 1990s large areas of meadows and arable land were gradually excluded from land use and exploitation. At present almost all coastal villages in this area have lost their agricultural character and became tourist resorts (Dębki, Karwia and Karwieńskie Błota II). The pressure of recreational use has led to uncontrolled development and gradual expansion of all kind of settlements and camping sites within the area of former peatbog habitats.

2.7. General features of contemporary vegetation

In the study area communities of the *Molinio-Arrhenatheretea* class prevail, represented mainly by wet meadows and pastures (*Molinion* and *Calthion*). Forest and shrub cover now more than 20% of the study area. This includes swamp forests in raised bogs that have been drained and planted with coniferous (pine, spruce) or broadleaved trees (birch, alder, aspen). Communities of raised bogs and transitional mires were preserved only as remnants and cover small patches of land. They are represented by *Sphagnum* communities with cross-leaved heath (*Erico-Sphagnetum medii*), moist heathlands (*Ericetum tetralicis* community) and *Rhynchosporetum albae* with the occurrence of *Rhynchospora fusca* (Herbichowa 1972; Budyś 2001). Sedge communities of the *Caricetalia nigrae* order, representing vegetation of fens, are considerably wide distributed. Phytocoenoses of the *Nardo-Callunetea* class developed mainly on fragments of Bielawskie Błoto, where the soil moisture had been badly disturbed, and are also scattered at the edges of forests and sandy roads. True rush communities (*Phragmition*) developed along larger water bodies and in drainage ditches and channels. Sedges (*Magnocaricion*) occupied the wet parts of the area, e.g. in Czarna Wda Valley and on Piaśnickie Łąki meadows. Aquatic communities (*Lemnetea* and *Potametea*) were observed mainly in drainage ditches, channels and rivers. Lakes and astatic water bodies have oligo- or mesotrophic character and are the habitat of species of *Utricularietea intermedio-minoris* and *Littorelletea uniflorae* classes. On temporary wet mineral habitats, e.g. in potholes of ground roads, phytocoenoses of the *Isoëto-Nanojuncetea* class develop. Communities of silt-covered soils (*Bidentetea tripartiti*) cover slightly more fertile and usually more moist habitats, mainly the embankments of drainage ditches. Small patches of communities with the species of the *Koelerio glaucae-Corynephoretea canescentis* class were encountered, e.g. on mineral hills in the region of Łąki Dębkowskie. Among segetal communities of weeds the *Centauretalia cyani* order prevailed. Ruderal vegetation is represented by communities of *Artemisietea* and *Agropyretea intermedio-minoris* classes and *Sisymbrietalia* and *Plantaginetalia majoris* orders.

3. MATERIALS AND METHODS

Materials and methods of flora feature analysis

Sources of floristic data and investigation periods. Contemporary vascular plant flora was listed during the author's field research (Budyś, unpubl.) carried out in 2000–2004 and supplemented with data from other up-to-date investigations: Herbichowa *et al.* (2001) and Minasiewicz *et al.* (2004). The studied area was divided into 122 squares 1 km × 1 km belonging to six squares 10 km × 10 km within an ATPOL grid squares (Zając A. 1978): AC 36, 37, 38, 46, 47, 48. In each of these, the species and their abundance were noted from all habitats occurring there. The planted species were omitted. A single square 1 km × 1 km was regarded as a single species locality. There were 4923 floristic relevés made in total. The locality of each relevé was noted in an aerial photograph (Aerial photographs 1996-1997) or saved in a GPS receiver. The contemporary floristic list was completed with all available data from previous research – 42 published and unpublished sources concerning the plant cover of the studied area were used (Budyś 2005). Because of the fragmentary character of archival data, the exact time of extinction or settlement of particular plant species was impossible to define. Despite this, some stages of flora transformation were analysed. Consequently, there were five investigation periods distinguished: (I) 1809-1896, (II) 1897-1940, (III) 1941-1979, (IV) 1980-1996, (V) 1997-2004.

Floristic data base and species classifications. There are 81019 records in the floristic data base – 74425 pertaining to contemporary flora and 6594 to historical one. The plant names, with a few exceptions, follow Mirek *et al.* (2002).

According to the number of species localities, six classes of frequency were defined (Table 1). Sociological groups of species (Table 2) are based on phytosociological classification of Matuszkiewicz (2001) and, in the case of mire species, of Dierssen (1982). All species with undefined phytosociological amplitude are grouped in the 'other species' class.

The geographic-historical classification of species follows Kornaś (1981) and Mirek (1981). Anthropophytes are divided into archaeophytes, kenophytes (epecophytes, hemiagriophytes, holoagriophytes) and diaphytes (with ephemeral species). The following sources of information about the geographic-historical status of species in the Pomorze

Table 1
The rules of defining frequency classes

Frequency class	Number of localities	% of localities	Definition of frequency
I	1-5	1-3	very rare
II	6-17	4-11	rare
III	18-35	12-24	widespread
IV	36-60	25-40	frequent
V	61-90	41-61	very frequent
VI	>90	>61	common

region were used: Kornaś (1968), Zając E.U. & Zając A. (1975), Zając A. *et al*. (1998), Markowski (unpubl. data). To assess the degree of flora transformation the following indices of anthropogenic changes in flora were used (Jackowiak 1990): anthrophytisation index (W_{an}), archaeophytisation index (W_{arch}), kenophytisation index (W_{ken}), index of flora modernisation (W_m) and index of fluctuation changes (W_f).

According to the classification of Raunkiaer (1905), six groups of life forms were defined: phanerophytes, chamaephytes, geophytes, hemicryptophytes, hydrophytes (with helophytes) and terophytes.

Apophytism index (I_{ap}) and naturalisation index (I_{nat}) were used to assess the dynamic tendencies among species in contemporary flora (Jackowiak 1990). In the analysis, species that were not settled and species of low frequency (with less then 10 localities) were not included.

Habitat classification in respect to status of hemeroby

The hemeroby scale (Jalas 1955; Sukopp 1972, 1976; Kowarik 1988) takes into account the range of anthropogenic changes in ecosystems, judged on habitat and phytosociological and floristic criterions. In the present work, the six-level scale of hemeroby proposed by Sukopp (1972) was detailed by division mesohemerobic and euhemerobic degrees into sub-grades. It was also assumed that ahemerobic and metahemerobic degrees were not represented within the studied area. Finally, the used hemeroby scale appears as follows:

1. Oligohemerobic habitats – no direct anthropic pressure, no significant changes in soil or hydrological conditions, natural plant cover (e.g. pools and their shores, moist heathlands with *Erica tetralix*).

2. Mesohemerobic habitats – habitats changed by human activity, the influence of anthropic pressure indirect (drainage), direct but periodical (e.g. peat exploitation, management of drainage system) or direct and permanent (hay-meadow farming, forestry) or habitats changed by natural factors such as animals burrowing. The soil substratum transformed by desiccation (moorshing). Sub-grades:

- α-mesohemerobic – habitats with more or less natural plant cover, no direct form of human pressure or pressure periodical (e.g. terrestrialized pools, post-exploitation digs);

Table 2
Sociological groups in the flora of studied area (symbols in Roman numerals). Phytosociological classification after Matuszkiewicz (2001)

Sociological groups		Phytosociological classification
Oligo- and mesotrophic water species (I)		*Littorelletea, Utricularietea*
Eutrophic water and spring species (II)		*Lemnetea, Potametea, Montio-Cardaminetea*
Raised bog and transitional mire species, swamp pine forest species, swamp birch forest species (III)		*Oxycocco-Sphagnetea, Scheuchzerietalia palustris, Vaccinio uliginosi-Pinetum sylvestris, Betuletum pubescentis*
Fen species (IV)	poor fen (IVa)	*Scheuchzerio-Caricetea nigrae, Caricetalia nigrae*
	neutral and rich fen (IVb)	*Caricetalia davallianae*
Swamp alder forest species and sedge communities species (V)		*Alnetea glutinosae, Magnocaricion*
Rushes species and species of river's bank (VI)		*Phragmitetea, Phragmition, Sparganio-Glycerion fluitantis*
Moist mineral soil and silt-covered soil species (VII)		*Isoëto-Nanojuncetea, Bidentetea tripartiti*
Meadow, tall herbs community and pasture species (VIII)	moist (VIIIa)	*Molinio-Arrhenatheretea, Molinietalia, Trifolio fragiferae-Agrostietalia stoloniferae*
	semi-dry (VIIIb)	*Arrhenatheretalia*
Heathland species (IX)		*Nardo-Callunetea*
Sandy grassland and dune species (X)		*Koelerio glaucae-Corynephoretea canescentis, Ammophiletea*
Termophilous forest-edge species and xerothermic grassland species (XI)		*Festuco-Brometea, Trifolio-Geranietea sanguinei*
Rich deciduous forest and shrub species (XII)		*Querco-Fagetea, Salicetea purpureae, Rhamno-Prunetea*
Pine forest and acid oak forest species (XIII)		*Vaccinio-Piceetea, Quercetea robori-petraeae*
Salty marshes species (XIV)		*Asteretea tripolium, Cakiletea maritimae*
Synanthropic habitat species (XV)	ruderal (XVa)	*Artemisietea, Agropyretea intermedio-repentis, Sisymbrietalia*
	trampled places (XVb)	*Plantaginetalia majoris*
	clearings (XVc)	*Epilobietea angustifoli*
	crop land (XVd)	*Stellarietea mediae, Centauretalia cyani, Polygono-Chenopodietalia*
Other species (XVI)		taxa with wide sociological amplitude

– β-mesohemerobic – spontaneous vegetation in significantly disturbed habitats or habitats with semi-natural and anthropogenic phytocoenoses, anthropic pressure irregular (e.g. forests and shrubs, non-surfaced ground roads);
– γ-mesohemerobic – habitats with semi-natural phytocoenoses formed by regular anthropic pressure such as hay-meadow farming (e.g. drainage ditches, meadows, mown sedge communities, pastures, sandy grasslands).

3. Euhemerobic habitats – disturbed by permanent and intensive human pressure, with ruderal and segetal vegetation. Soil and hydrological conditions significantly changed. Sub-grades:

- α-euhemerobic – habitats changed by transportation, settlement, tourism, soil substratum disturbed by allochtonic material disposal or fires (e.g. hard-surfaced roads, built-up area);
- β-euhemerobic – habitats formed by agriculture or waste disposal sites, soil substratum significantly changed or entirely anthropogenic, floristic instability (waste disposal sites, arable fields, gardens).

4. Polyhemerobic habitats – anthropogenic habitats, artificial substratum (concrete, asphalt), instable synanthropic vegetation, pioneer vegetation.

Habitat classification with respect to its genesis and forms of land use

Ecological types of mire and forms of anthropic pressure which influenced the flora of studied sites are the basis of defining 35 types of habitat (Table 3). As well as the habitats formed or significantly transformed by direct forms of anthropic pressure, the habitats influenced by drainage as well as more or less natural habitats were considered.

Materials and methods of environmental change analysis

Analysis of chosen elements of environment and reconstruction of their changes was based on the following materials:

- topographic maps: 1810 (surveyed in 1796-1806), 1889 (surveyed in 1862-1875), 1911 (surveyed in 1877), 1918 (surveyed in 1877), 1935 (surveyed in 1928), 1940, 1941, 1942 (surveyed in 1934-1939);
- maps of geological deposits (Detailed geological map... 1978, 1985, 2002);
- drafts from geological documentation of peat deposits (Geological documentation... 1957, 1963, 1968);
- archival and up-to-date aerial photographs (1947, 1958, 1964, 1976, 1984, 1996-1997),
- digital vector topographic map (Topographic map 2000-2002).

Topographic maps 1889 and 1940-1942, aerial photographs from 1964 and 1996-1997 and geological maps were chosen for detailed analyses with GIS techniques (ArcGis 8.3 software). These cartographic materials were transformed into raster layers (UTM projection, 34N zone) by rectification. Screen digitisation allowed the creation of several vector maps: maps of land cover classes in the above-mentioned periods of time, maps of former road systems and hydrological networks (based on Topographic map 1889), maps of geological deposits, and maps of the boundary between raised bogs/transitional mire and fen habitat. There were nine classes of land cover distinguished with regard to type of land use or the type of dominating phytocoenosis: (1) the area with no signs of disturbances, (2) pools, (3) forests, (4) shrubs, (5) agricultural land (meadows, pastures, arable fields), (6) post-exploitation digs, (7) post-exploitation digs with shrubs, (8) built-up areas, (9) other disturbances (area disturbed by ploughing, turf cutting or fire). The maps of land cover classes were used to create a synthetic map of the age of disturbances according to the cartographic model presented in Figure 3.

Table 3
Forms of anthropic pressure changing habitats within raised bog/transitional mire and fen

Symbol of habitat type		Anthropic pressure	Type of habitat
Raised bog/ transitional mire habitat	Fen habitat		
A_1	B_1	none	pools, canals waters, sedge communities, *Myrica gale* communities, moist heathlands
A_2	B_2	peat exploitation	post-exploitation digs and their embankments
A_3	-	drainage	terrestrialized pools
A_4	B_4	drainage	forests
A_5	B_5	drainage	shrubs
-	B_6	drainage	sandy grasslands
A_7	B_7	drainage	dry heathlands
A_8	B_8	drainage	burnt places
-	B_9	intensive hay-meadow farming	mown and sown meadows
A_10	B_10	extensive hay-meadow farming	mown meadows and pastures
A_11	B_11	former hay-meadow farming or grazing	abandoned meadows and pastures
A_12	B_12	forestry	trees plantations, clearings
A_13	B_13	creating and conservation of drainage system	drainage ditches and their embankments
-	B_14	rivers regulation	canals banks
A_15	B_15	agriculture	crop fields and abandoned fields
-	B_16	human settlements	cottage surroundings, by-fence habitats, flowers beds, camping sites
A_17	B_17	transport	ground roads and roads sides, trampled places
A_18	B_18	waste disposal	waste disposal places
A_19	B_19	allochtonic substrate disposal	allochtonic mineral grounds
A_20	-	other disturbances of soil surface	ploughed or rooted places
-	B_21	creating of artificial surfaces	concrete and asphalt surfaces

Some environmental features were analysed within a grid of 1 km x 1 km squares (detailed ATPOL grid). In order to prepare the digital map of squares a draft of the ATPOL map (Zając A. & Zając M. (eds.) 1996-1998) was digitised and saved as a vector layer. Then the vector model of the grid was complemented by linear interpolation of grid nodes in a Cartesian coordinate system.

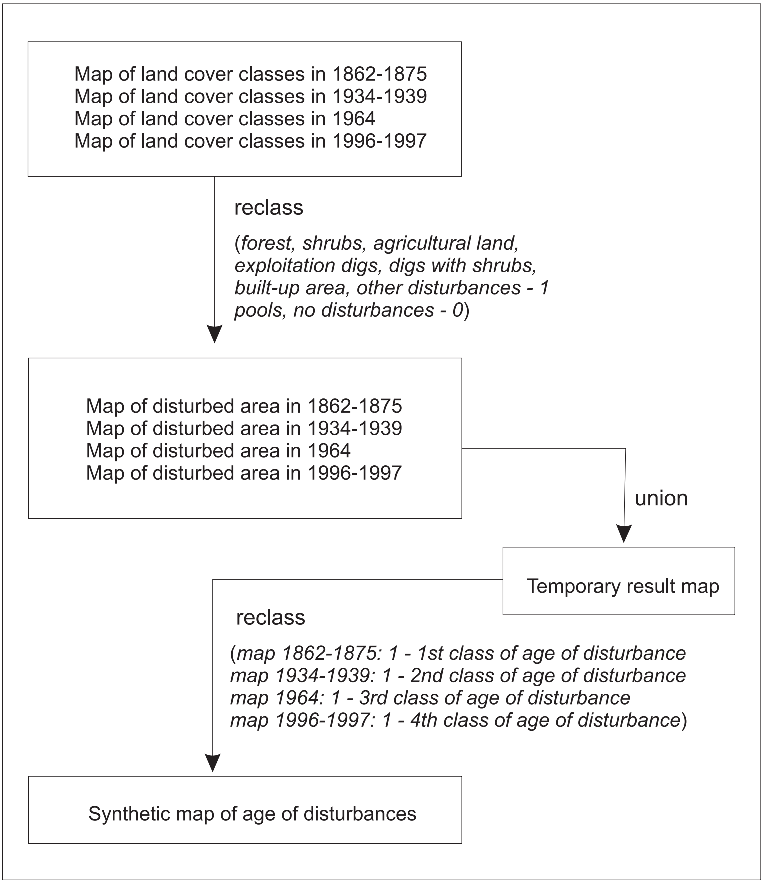


Fig. 3. Cartographic model used for preparation of synthetic map of disturbances' age (in reclass options the new value of attribute of each class was given after hyphen)

Methods of analysis of relationship between spatial differentiation of flora and environment features

The multivariate analyses and GIS methods were applied to define the correlation between flora and environmental features.

The following multivariate analyses, made with *Canoco for Windows* 4.5 software, were used: DCA (detrended correspondence analysis), PCA (principal components analysis), RDA (redundancy analysis) and CA (correspondence analysis). The type of analysis was chosen with regard to the rules given by Ter Braak & Prentice (1988), Ter Braak & Šmilauer (2002) and Lepš & Šmilauer (2004). In Table 4 a short summary of the options of each analysis is given. The results were interpreted mainly by studying the relationship between particular variables and sample scores (inter set correlation), as well as correlations (r) between variables (Jongman *et al*. 1987; Piernik 2005). The statistical significance of the RDA model and the significance of each variable in the forward selection procedure was tested using the Monte Carlo test ($p<0.05$) (Ter Braak & Prentice 1988). In order to assess which part of variability in species data set can be explained by geological factors

Table 4
Researched problems and methods applied to solve them

Problem	Research procedure	
The effect of particular forms of anthropic pressure on today flora composition	Method	CA
	Samples	types of habitats within raised bog/transitional mire vs. fen, influenced by analogical form of anthropic pressure
	Species data	species composition with number of records of each species (sum of records of particular species in given habitat divided by sum of records of all species noted in this habitat)
	Supplementary variables	1. mean values of Zarzycki indicators (TR, R, H, L, W), 2 – sociological structure, 3. living forms, 4 – anthropophytisation index, 5 – number of species
	Options	inter-sample distance, Hill's scaling
Correaltion between spatial structure of the flora and environment	Method	PCA
	Samples	sample fields (≥ 50 species in flora only)
	Species data	floristic composition (binary)
	Supplementary variables	1. percentage of the area of bog/transition mire vs. fen, 2. percentage of the area of land cover-classes, 3. percentage of the area of age-classes of disturbance, 4. percentage of the area of geological deposits' type, 5. the length of roads and the length of ditches, 6. number of relevés made in habitats influenced by given form of human pressure, 7. mean values of Zarzycki indicators (TR, R, H, L, W), 8. sociological structure of the flora, 9. geographic-historical structure of the flora, 10. percentage of species living forms, 11. number of species
	Options	centre by species, inter-sample distances, species scores divided by standard deviation
Effects of natural and anthropogenic variables on contemporary flora	Method	RDA, variance partitioning
	Samples	sample fields (≥ 50 species in flora only)
	Species data	floristic composition (binary)
	Environmental variables	Step I ▸Environmental variables: 1. percentage of the area of bog/transitional mire vs. fen, 2. percentage of the area of geological deposits' type, 3. percentage of the area of land cover-classes, 4. percentage of the area of age-classes of disturbance, 5. the length of roads and the length ditches Step II ▸Environmental variables – variables connected with type of sediments: 1. percentage of the area of bog/transitional mire vs. fen , 2. percentage of the area of geological deposits' type; Covariables – variables connected with environment disturbances: 1. percentage of the area of land cover-classes, 2. percentage of the area of age-classes of disturbance, 3. the length of roads and the length ditches Step III ▸Environmental variables – variables connected with environment disturbances (as above); Covariables – variables connected with type of sediments (as above)
	Options	centre by species, inter-sample distances, species scores divided by standard deviation, Monte Carlo test on I axis & on the trace: reduced model, unrestricted permutation, number of permutation = 499

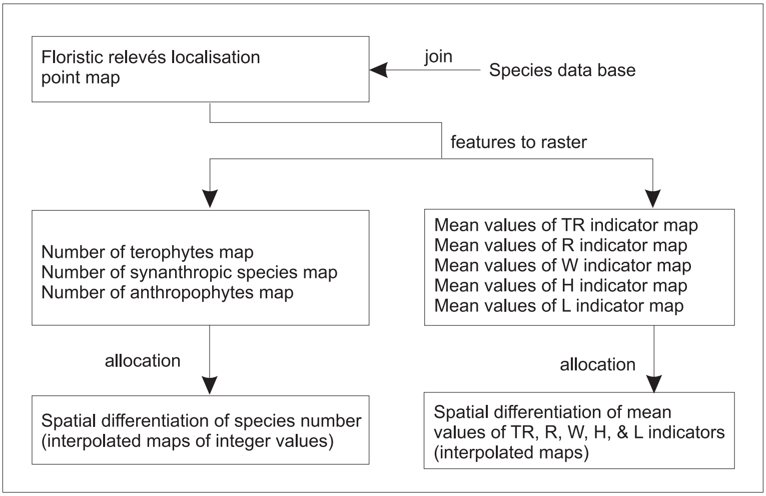


Fig. 4. Cartographic model used for preparation of maps of spatial variation of terophytes, synanthropic species and anthropophytes and mean values of TR, R, W, H and L indicators (in reclass options the new value of attribute of each class was given after hyphen)

and which by anthropogenic factors, the procedure of variance partitioning based on RDA results (see Table 4) was applied (Lepš & Šmilauer 2004).

In localities of floristic relevés the following flora features were extracted: the number of species typical to synanthropic habitats, the number of anthropophytes and the number of terophytes. This was then used as the basis for indicator maps preparation (Fig. 4). The analogous procedure was used to elaborate maps of mean values of given ecological indicators (Zarzycki *et al*. 2002): trophy (TR), soil acidity (R), soil moisture (W), light (L) and humus content (H). The calculation of mean values was simplified: for cases in which species occur in a range of values the median one was chosen, and in each floristic relevé the arithmetical mean was calculated. The spatial differentiation of flora features was presented in maps of continuous values elaborated by interpolation technique. The missing values were interpolated with a Euclidean allocation function in which 'No Data' cells were given the value of the closest source cell (Esri 2001-2002; Urbański 2001).

4. RESULTS

4.1. Range of changes in flora

4.1.1. Species recession

During the past 198 years in the flora of vascular plants of the Błota Przymorskie Plain and Płutnica Valley 958 taxa were listed, while the contemporary flora of the studied area consists of 808 taxa. Total flora of raised bogs and transitional mire habitat consists of 570 taxa,

Table 5
Percentage of sociological groups among extinct species

Sociological group*	Number of species	Percentage [%]
I	8	8.6
II	6	6.5
III	8	8.6
IV	6	6.5
V	3	3.2
VI	4	4.3
VII	3	3.2
VIIIa	8	8.6
IX	7	7.5
X	4	4.3
XI	2	2.2
XII	1	1.1
XIII	3	3.2
XIV	2	2.2
XV	3	3.2
XVI	25	26.9
Sum	93	100.0

* – for explanation see Table 2

the total flora of fens – of 927 taxa, while 459 and 792 vascular plant species, respectively, were noted in the contemporary flora.

Among 150 species, which at present were not found in the studied area, 93 (ca 10% of the whole flora) can be considered as extinct (not recorded since at least 1979). The remaining 57 species were included into the group of undetermined status (common species, probably overlooked during the present survey, species probably incorrectly reported in previous studies, and species which were not permanently established in the flora).

Among locally extinct species (Table 5), a significant proportion have taxa of wide phytosociological amplitude (XVI), aquatic species (I and II), mire species (III and IV) and species of wet meadows (VIIIa).

Species associated with aquatic habitats and habitats of high groundwater level (groups I-VIIIa) comprise 49% of all extinct species. Detailed analysis of retreat of species from these sociological groups, conducted at the level of syntaxa showed their internal differentiation (Fig. 5):

- in the group of species of oligo- and mesotrophic waters (I) greater losses were noted among taxa of oligotrophic habitats (*Littorelletea* class – 7 species) than in mesotrophic (*Utricularietea* class – 1 species);
- among species of eutrophic waters and springs (II) losses considered almost exclusively representatives of aquatic macrophytes (*Potametea* class – 6 species);

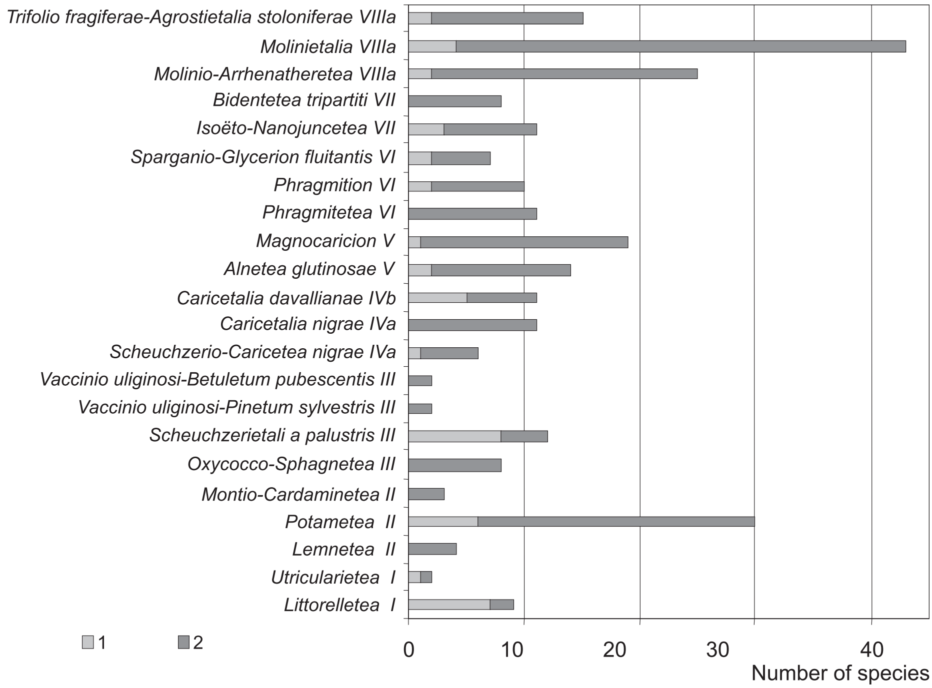


Fig. 5. The number of extinct species (1) versus contemporary living ones (2) in given syntaxa. Beside the name of syntaxa the symbol of sociological group is given (I-VIIIa, explanations see Table 2)

- among species of raised bog complex (III) only those representing order *Scheuchzerietalia palustris* (8 species), which at a raised bog are an element of hollows, were regarded as locally extinct;
- relatively greatest losses among fen species (IV) were recorded in the group associated with neutral and rich habitats (order *Caricetalia davallianae* – 5 species);
- in groups of swamp alder forest and sedge communities (V and VI) only a slight decrease in the number of species was recorded (3 and 4 species, respectively);
- retreat in the group of moist mineral soil and silt-covered soil species (VII) consider only species of *Isoëto-Nanojuncetea* class (3 species);
- locally extinct species connected with wet meadows (VIIIa) belong mostly to communities of purple moor-grass meadows and riparian tall herbs communities (order *Molinietalia* – 4 species).

Among extinct taxa the greatest proportion have hemicryptophytes (43 species, 46%), hydro- and helophytes are also well represented (22 species, 24%) as well as terophytes (11 species, 12%). In comparison with the biological structure of total flora, low proportion of phanerophytes (only 3 species) drawn attention. The greatest regression occurred in the group of hydro- and helophytes – locations of 22 taxa, which comprise 25.8% of all aquatic species, were not confirmed.

Disappearance of species considers mainly native taxa. Losses among metaphytes are negligible (2 archaeophytes and 1 kenophyte species).

Analysis of disappearance of species within defined investigation periods showed that the greatest losses in flora were stated after 1940 (in 1897-1940 – 63 taxa of vascular plants were recorded for the last time, in 1809-1896 – 17 species and in 1941-1979 – only 12 species). High proportion among species recorded for the last time in the second investigation period (1897-1940) have taxa of oligo- and mesotrophic waters (I), bog and fen species (III and IV), species of moist meadows (VIIIa), heathlands (IX), and species of wide phytosociological amplitude (XVI).

4.1.2. Enrichment of flora and characteristics of contemporary flora

Number of species in consecutive investigation periods. Because of a lack of complete documentation of flora in particular investigation periods it was not possible to follow all stages of its enrichment with environmentally and geographically alien species. Generally, it can be assumed that since 1809 the number of vascular plant species in the flora of the studied area has gradually increased. In consecutive investigation periods the following numbers of species were noted: 1809-1896 – 327 species; 1897-1940 – 545 species; 1941-1979 – 366 species (in this period surveys covered only selected parts of the area); 1980-1996 – 619 species; 1997-2004 – 808 species.

It can be assumed that the rise of number of species in consecutive investigation periods resulted both from real establishment of species and better recognition of flora by botanists.

The total number of species recorded in the studied area is 33% of flora of vascular plants of Poland, considering that it is recently estimated at 2980 species (Mirek *et al.* 2002).

Geographic-historical structure of the flora. In the present flora of the studied area, 612 spontaneophytes and 196 anthropophytes occur (Table 6). In the group of species of foreign origin, diaphytes prevail (76 species). Their presence is most often connected with accidental bringing of their diaspores with garbage and organic waste. This considers mainly decorative plants, such as e.g. *Callistephus chinensis*, *Salvia viridis* and vegetables, e.g. *Lycopersicon esculentum*. The source of diaspores of diaphytes might be also supplemental food left for wild animals by hunters. Diaphytes occupy also habitats around cottages and along communication paths (e.g. *Avena sativa*, *Raphanus sativus*).

Table 6
Percentage of anthropophytes in contemporary flora

Geographic-historical group		Number of species	Percentage [%]
Spontaneophytes		612	76
Archaeophytes		61	8
Kenophytes	Epecophytes	40	5
	Hemiagriophytes	8	1
	Holoagriophytes	11	1
Diaphytes		76	9
Sum		808	100

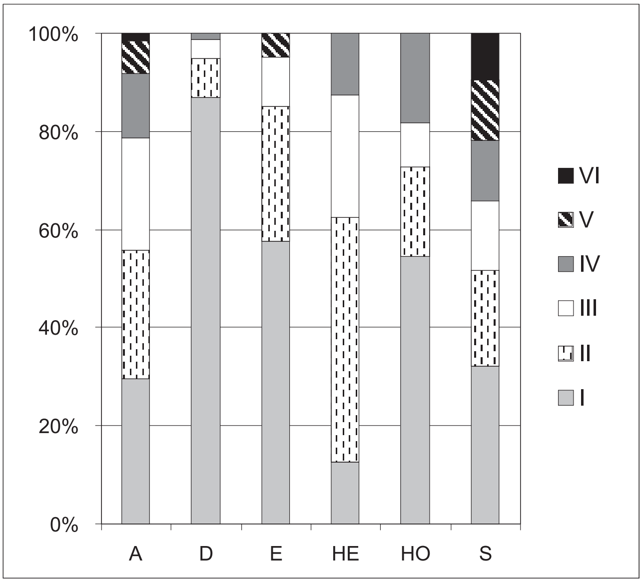


Fig. 6. The frequency of species in given geographic-historical groups I – very rare; II – rare; III – widespread; IV – frequent; V – very frequent; VI – common species; S – spontaneophytes; A – archaeophytes; D – diaphytes; E – epecophytes; HE – hemiagriophytes; HO – holoagriophytes

The group of archaeophytes comprises 61 species. They are connected mainly with arable land (e.g. *Aphanes arvensis*, *Bromus secalinus*) or with ruderal habitats (e.g. *Conium maculatum*, *Leonurus cardiaca*). They are often recorded also at areas of disturbed soil surface, and along drainage ditches.

There are 59 species of kenophytes recorded in the studied area. In majority they are established in synanthropic habitats (40 species of epecophytes, e.g. *Bromus carinatus*, *Echinocystis lobata*, *Impatiens glandulifera*). Semi-natural and natural habitats support 30% of kenophytes, including 8 species of hemiagriophytes (e.g. *Epilobium ciliatum*, *Lolium multiflorum*) and 11 species of holoagriophytes (e.g. *Elodea canadensis*, *Picea abies*).

In the group of archaeophytes and spontaneophytes proportion of species of particular frequency classes does not depart substantially from the species frequencies in the total contemporary flora (Fig. 6). More than a half of taxa in these groups are rare and very rare species. Among diaphytes and agriophytes common and very frequent species are completely missing. The total proportion of species from I and II frequency class is the highest among diaphytes (94%), and among kenophytes it ranges from 62% (hemiagriophytes) to 84% (epecophytes).

Sociological structure of the flora. In contemporary flora of the study area, mires taxa (groups III, IVa, IVb) constitute 4.7% of the total number of species (Table 7). All species associated with high water level, i.e. aquatic, mire and rush plants (groups I-VI) comprise 15.6% of flora. Taxa of wide sociological amplitude (group XVI) have the greatest proportion of the flora (33%). Slightly more than 19% of flora is formed by synanthropic species (XV), among which the most numerous are species of ruderal habitats (74 species) and crop land weeds (64 species). Relatively high proportion of flora have meadow species (VIII); in this group species of wet meadows are significantly more numerous (VIIIa – 9.3% of flora) than species of semi-dry habitats (VIIIb – 3.2% of flora). A significant proportion (8.3%) have also species of rich deciduous forest and shrubs (group XII).

Table 7
Sociological structure of flora

Sociological group*	Number of species	Percentage [%]
I	3	0.4
II	31	3.8
III	16	2.0
IVa	16	2.0
IVb	6	0.7
V	30	3.7
VI	24	3.0
VII	16	2.0
VIIIa	75	9.3
VIIIb	26	3.2
IX	17	2.1
X	24	3.0
XI	19	2.4
XII	67	8.3
XIII	16	2.0
XIV	2	0.2
XV	154	19.1
XVI	266	32.9
Sum	808	100.0

* – for explanation see Table 2

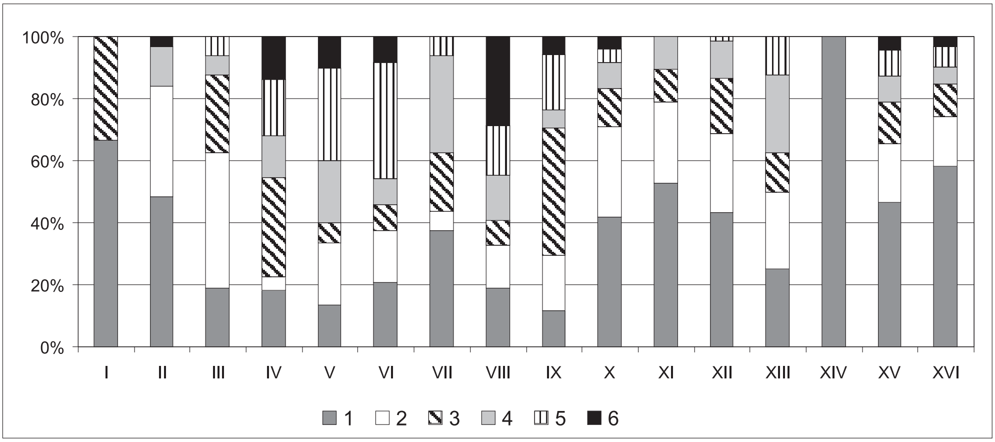


Fig. 7. The frequency of species in given sociological groups
1 – very rare; 2 – rare; 3 – widespread; 4 – frequent; 5 – very frequent; 6 – common species; other symbols see Table 2

Defined sociological groups of species are differentiated in regard to proportions of frequency classes (Fig. 7). The typical feature of species characteristic of oligo- and mesotrophic waters (I), neutral and rich fens (IVb) and of salty marshes (XIV) is a complete lack of common and very frequent taxa. Very rare and rare species predominate among taxa connected with eutrophic waters (II), raised bogs (III), sandy grasslands (X), termophilous forest-edges and xerothermic grasslands (XI), rich deciduous forests and shrubs (XII), synanthropic habitats (XV), and among taxa with wide sociological amplitude (XVI). Frequent, very frequent and common species are the majority of the group of poor fen species (IVa), swamp alder forest and sedge communities species (V), rushes species (VI) and meadow species (VIII). The group of poor fen species (IVa) draws attention due to the fact that any species of I or II frequency class has been stated in this group.

The majority of defined sociological groups are formed of native species, while taxa of foreign origin play greater role only in groups of species of synanthropic habitats (XV) and of wide sociological amplitude (XVI).

Biological structure of the flora. In contemporary flora of the studied area hemicryptophytes (41%) and terophytes (25%) have the highest representation. Phanerophytes, geophytes and hydro- and helophytes are 13%, 9% and 8% of the flora, respectively. The least numerous group are chamaephytes, which comprise 4% of the flora (Table 8).

In comparison with the flora of Poland, perennial plants have much less importance, while phanerophytes, terophytes and chamaephytes have much greater importance. Higher representation of trees and shrubs is connected with expansion of species of foreign origin, which are in majority considered as non-established elements of flora. Abundant occurrence of annual and biannual plants in the studied area is connected mainly with the presence of anthropogenic habitats, such as "islands" of mineral soils, ground roads and arable land. For example, the proportion of terophytes in the flora of the Błota Przymorskie Plain and Płutnica Valley is slightly higher than in the area of the Słowiński National Park, which is only slightly changed by anthropic pressure. Furthermore, it is lower than in the eastern part of the Gnieźnieńskie Lakeland, where arable land is a dominant element of the landscape (Table 8).

Analysis of the spectrum of life forms in determined sociological groups showed that in these groups of species, which can be considered as the natural elements of flora (groups I-VI), hemicryptophytes and hydro- and helophytes prevail, while chamaephytes and

Table 8

Living forms of species in the flora of studied area, flora of Słowiński National Park (Piotrowska *et al.* 1997), flora of Gnieźnieńskie Lakeland (Chmiel 1993) and flora of Poland (Pawłowska 1959)

<table>
<tr><th>Living forms</th><th colspan="2">Błota Przymorskie Plain and Płutnica Valley [%]</th><th colspan="2">Słowiński National Park [%]</th><th colspan="2">Gnieźnieńskie Lakeland [%]</th><th>Poland [%]</th></tr>
<tr><td>Phanerophytes</td><td colspan="2">13</td><td colspan="2">12</td><td colspan="2">10</td><td>9</td></tr>
<tr><td>Chamaephytes</td><td colspan="2">4</td><td colspan="2">6</td><td colspan="2">4</td><td>2</td></tr>
<tr><td>Hemicryptophytes</td><td>41</td><td rowspan="3">58</td><td>39</td><td rowspan="3">59</td><td>39</td><td rowspan="3">59</td><td rowspan="3">67</td></tr>
<tr><td>Geophytes</td><td>9</td><td>11</td><td>13</td></tr>
<tr><td>Hydro- and helophytes</td><td>8</td><td>9</td><td>7</td></tr>
<tr><td>Terophytes</td><td colspan="2">25</td><td colspan="2">23</td><td colspan="2">27</td><td>22</td></tr>
</table>

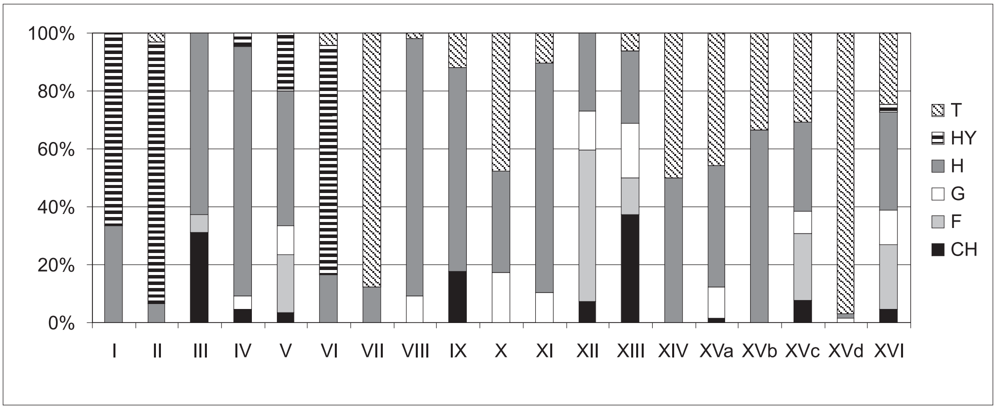


Fig. 8. Percentage of living form group of species in each sociological group
CH – chamaephytes; HY – hydro- and helophytes; G – geophytes; F – phanerophytes; T – terophytes; H – hemicryptophytes; other symbols see Table 2

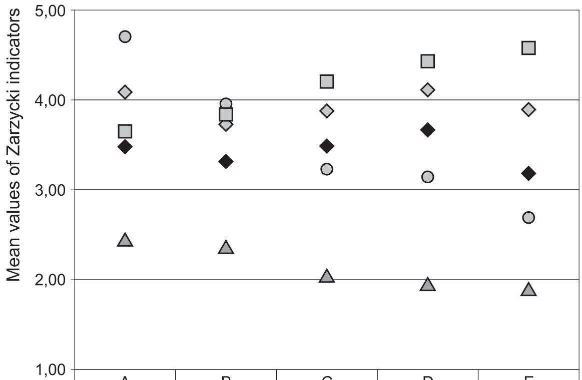
phanerophytes are considerably less common, and geophytes or terophytes have only slight representation (Fig. 8). Enrichment of the flora with phanerophytes, geophytes and terophytes species can be considered as an indicator of anthropogenic disturbance to the environment. Geophytes are relatively well represented among species of sandy grasslands (X), forests (XII, XIII) and termophilous forest-edges (XI), while phanerophytes are abundant in the group of taxa of rich deciduous forest or shrubs (XII) and clearings (XVc). Terophytes are numerously represented in the group of species of ruderal habitats (XV), especially of crop land (XVd), moist mineral soils and silt-covered soils (VII) and among sandy grasslands and dunes species (X).

4.1.3. Dynamic tendencies of selected groups of species

Apophytism of spontaneophytes. The dynamics of native species is reflected by e.g. their ability to occupy strongly transformed, eu- and polyhemerobic habitats. In this paper this tendency is described as the index of apophytism (I_{ap}).

A lack of tendency to occupy strongly transformed habitats ($I_{ap}=0$) was stated only in case of 34 taxa (6% spontaneophytes). Almost 70% of species from this group are associated with aquatic habitats and habitats of high groundwater level. This considers taxa typical of eutrophic waters (II – e.g. *Lemna trisulca*, *Myriophyllum verticillatum*); raised bogs, acid swamp forests and fens (III, IV – e.g. *Carex lasiocarpa*, *Dryopteris dilatata*); swamp alder forests and sedges communities (V – e.g. *Osmunda regalis*, *Thelypteris palustris*); wet meadows (VIIIa – e.g. *Carex cespitosa*, *Cnidium dubium*). The remaining taxa, which do not show any tendency of apophytism are associated with forests (XII, XIII – e.g. *Ranunculus auricomus*, *Pyrola minor*) or belong to a group of wide sociological amplitude species, e.g. *Dactylorhiza maculata*, *Platanthera bifolia*, *P. chlorantha*.

The most numerous group among native species (225 species, 38% of spontaneophytes) are taxa of a very low tendency for apophytism ($1\% \leq I_{ap} \leq 25\%$). This group is represented by e.g. species typical of wet meadows (VIIIa – e.g. *Achillea ptarmica*, *Molinia caerulea*);



	A	B	C	D	E
○ W	4,69	3,94	3,21	3,13	2,68
◆ TR	3,47	3,31	3,48	3,67	3,18
◇ R	4,07	3,73	3,86	4,10	3,89
□ L	3,63	3,83	4,19	4,42	4,57
△ H	2,43	2,34	2,01	1,92	1,86

Fig. 9. Mean values of Zarzycki indicators in each apophytism class (A-E)
A – I_{ap}=0; B – 1%≤I_{ap}≤25%; C – 26%≤I_{ap}≤50%; D – 51%≤I_{ap}≤75%; E – 76%≤I_{ap}; W – soil moisture indicator; TR – trophy indicator; R – soli acidity indicator; L – light indicator; H – humus content indicator

raised bogs and acidophilous swamp forests (III, IV – e.g. *Andromeda polifolia*, *Calamagrostis stricta*) and heathlands (IX – e.g. *Calluna vulgaris*, *Viola canina*). Some synanthropic species also belong to this class (XV – e.g. *Epilobium hirsutum*, *Eupatorium cannabinum*, *Urtica dioica*).

Among 80 species showing a moderate tendency of apophytism (26%≤I_{ap}≤50%), which comprise 13% of spontaneophytes, a relatively high proportion have taxa typical of semi-dry meadows (VIIIb – e.g. *Leontodon autumnalis*, *Rumex thyrsiflorus*); ruderal habitats (XVa - e.g. *Calystegia sepium*, *Rubus caesius*); and clearings (XVc – e.g. *Calamagrostis epigejos*, *Senecio sylvaticus*).

Species of strong and very strong tendency of apophytism (51%≤I_{ap}) are 7% of spontaneophytes (44 species). This group is formed e.g. by taxa of ruderal (XVa) and segetal (XVd) habitats, sandy grasslands (X), termophilous forest-edges and xerothermic grasslands (XI), meadows (VIII), moist mineral soils and silt-covered soils (VII) and species of wide sociological amplitude (XVI). Strong tendency to apophytism (51%≤I_{ap}≤75%) is shown by e.g. *Juncus bufonius*, *Daucus carota*, *Bromus inermis*, *Artemisia vulgaris*, *Galeopsis tetrahit*. The following 14 species of spontaneophytes are in great extent associated with eu- and polyhemerobic habitats (76%≤I_{ap}): *Aethusa cynapium*, *Anchusa arvensis*, *Arctium minus*, *Arenaria serpyllifolia*, *Artemisia campestris*, *Chenopodium album*, *Erodium cicutarium*, *Juncus compressus*, *Medicago lupulina*, *Melilotus alba*, *Poa annua*, *Potentilla argentea*, *Spergularia rubra* and *Trifolium arvense*.

Described groups of spontaneophytes have been characterised by the mean values of Zarzycki ecological indicators (Zarzycki *et al*. 2002). Species which do not show any tendency for apophytism (I_{ap}=0) are associated with the most humid habitats, of a relatively high humus content and with relatively low light indicator (Fig. 9). The group of taxa showing very strong tendency for apophytism (76%≤I_{ap}) is characterised by the lowest values of moisture, trophy and humus content indicators. These species are adapted to colonise dry, mineral anthropogenic habitats, such as ground roads and arable fields.

Naturalisation of anthropophytes. Ability of species of foreign origin to invade natural and semi-natural (oligo- and mesohemerobic) habitats was described using naturalisation indicator (I_{nat}). In the analysis sporadic species (with 1-10 records) were not considered.

Only one species of foreign origin – *Veronica persica* was encountered exclusively on euhemerobic habitats ($I_{nat}=0$).

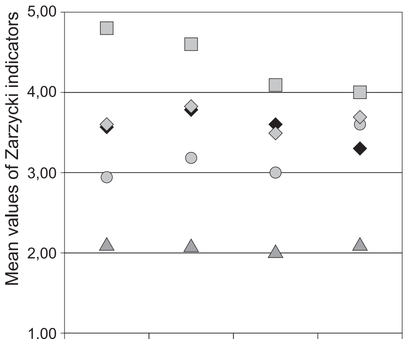
Relatively high proportion (21 species, 18%) among anthropophytes have taxa of weak abilities to occupy oligo- and mesohemerobic habitats ($1\% \leq I_{nat} \leq 25\%$). They are mostly archaeophytes associated with arable fields, e.g. *Anagallis arvensis*, *Anthemis arvensis* and ruderal habitats: *Descurainia sophia*, *Malva neglecta*.

Anthropophytes of medium tendency to invade natural and slightly transformed habitats ($26\% \leq I_{nat} \leq 50\%$) are also a numerous group (22 species, 18%). Archaeophytes associated with segetal habitats prevail among them, e.g. *Apera spica-venti*, *Lamium purpureum.* Taxa of wide sociological amplitude, e.g. *Conyza canadensis*, *Prunus cerasifera*, and species of ruderal habitats, e.g. *Impatiens glandulifera* also belong to this group.

Taxa of strong tendency to naturalisation ($51\% \leq I_{nat} \leq 75\%$) are 5% of all plants of foreign origin. This group consists of 6 species: kenophytes – *Epilobium ciliatum*, *Anthoxanthum aristatum*, *Sambucus racemosa*, *Malus domestica*, and archaeophytes – *Lamium album* and *Odontites verna*.

The strongest tendency to occupy oligo- and mesohemerobic habitats ($76\% \leq I_{nat}$) was shown by 5 species of kenophytes: *Elodea canadensis*, *Lolium multiflorum*, *Padus serotina*, *Picea abies* and *Pyrus communis*.

Analysis of the geographic-historical structure of distinguished naturalisation classes indicated that kenophytes showed remarkably stronger tendency to expansion to semi-natural habitats. Archaeophytes were represented mostly by specialised field weeds, and their mean naturalisation index is 25%. Kenophytes have much wider habitat and sociological amplitude and the mean value of the naturalisation index for them is 51%. Comparison of the highest values of naturalisation indicator of older and newer invaders confirmed clearly stronger expansiveness of kenophytes – it is 60% for archaeophytes (*Odontites verna*) and 100% for kenophytes (*Elodea canadensis*).



	A	B	C	D
○ W	2,95	3,18	3,00	3,60
◆ TR	3,58	3,79	3,60	3,30
◇ R	3,60	3,83	3,50	3,70
□ L	4,80	4,61	4,10	4,00
△ H	2,10	2,08	2,00	2,10

Fig. 10. Mean values of Zarzycki indicators in each naturalisation class (A-D)
A – $1\% \leq I_{nat} \leq 25\%$; B – $26\% \leq I_{nat} \leq 50\%$; C – $51\% \leq I_{nat} \leq 75\%$; D – $76\% \leq I_{nat}$; W – soil moisture indicator; TR – trophy indicator; R – soil acidity indicator; L – light indicator; H – humus content indicator

Analysis of mean values calculated from Zarzycki indicators (Zarzycki *et al*. 2002) for described groups of anthropophytes showed that these species which were the most successful in invading semi-natural habitats had lower light requirements and preferred slightly higher soil moisture than anthropophytes with low values of naturalisation indicator (Fig. 10).

4.2. Reasons for changes in flora

4.2.1. Reconstruction of changes in selected elements of environment

During recent two hundred years the whole coastal zone, including the studied area, was deeply transformed by human activity. Collected cartographic materials (topographic maps and aerial photographs), literature data and own observations revealed that the main forms of anthropopressure, which affected the stage of the natural environment, were: drainage works and regulation of rivers, meadows and pastures use, agriculture, peat exploitation, settlements, development of road networks, forestry and illegal waste disposal.

Archival topographic maps, which registered the stage of the study area in years 1862-1875 and 1934-1939 (Topographic map 1889, 1940-1942), and historical and current aerial photographs from 1964 and 1996-1997 allowed reconstructing successive stages of transformation of the environment (Figs 11-14). The analysis consisted of tracing the changes in area of 9 land cover classes (Table 9):

- the main tendency of changes was a gradual decrease of coverage of areas without signs of disturbance and, simoultanously, expansion of farmland and areas covered by woodland and shrub communities;
- from the first studied period farmlands were the dominant element of the landscape; their coverage increased gradually between 1862 and 1964, when it reached more than 50 km^2, and currently a slight decrease of its area to 48 km^2 was noted;
- areas of peat excavations covered the largest area in 1964; recently their area has decreased due to overgrowing post-exploitation digs with forest communities;
- during the initial period of studies, the coverage of non-disturbed areas was ca 43%, while at present it comprises as little as 4% of the studied area;
- as the effect of drainage, the coverage of water reservoirs decreased from ca 0.45 km^2 to 0.03 km^2 between 1862 and 2002;
- during the initial period of studies forests and shrubs covered neglectible area, while at present they cover in total ca 22% of the area;
- in the 1990s, a significant increase of built-up area was observed, with tenfold incraese of coverage since 1964;
- the coverage of areas where "other disturbances" were stated reached the highest value in 1964, which is associated mainly with extensive fires which occurred in this period.

Based on maps of land cover classes in four consecutive time periods, a synthetic map of the age of disturbances was prepared (Fig. 15). This map shows that more than 80% of the studied area has been disturbed already in the initial periods of studies, i.e. between 1862 and 1939. Areas disturbed later are mainly small patches located at the edges of raised and transitional mires – changed into arable land or overgrown by shrubs and woodlands after 1939.

Table 9
Area of land cover classes in given periods of time

Land cover class	1862-1875		1934-1939		1964		1996-1997	
	area [km^2]	%	area [km^2]	%	area [km^2]	%	area [km^2]	%
No signs of disturbance*	31.89	42.97	16.30	21.97	9.61	12.95	2.96	3.99
Pools	0.45	0.60	0.27	0.37	0.17	0.24	0.03	0.04
Forest	0.43	0.58	1.46	1.97	3.41	4.60	10.92	14.71
Shrubs	0.33	0.5	1.72	2.32	4.60	6.20	5.64	7.61
Agricultural land	38.51	51.90	50.92	68.62	51.20	69.01	48.54	65.42
Post-exploitation area	2.14	2.88	2.60	3.50	2.61	3.52	0.40	0.54
Post-exploitation area with shrubs	0.00	0.00	0.07	0.10	1.14	1.54	1.33	1.79
Built-up area	0.45	0.61	0.80	1.08	0.33	0.44	3.55	4.78
Other disturbances	0.00	0.00	0.07	0.09	1.13	1.52	0.84	1.13
Sum	74.20	100.00	74.20	100.00	74.20	100.00	74.20	100.00

* – all areas where any sign of human activity was recognizable on aerial photo

Comparison of the length of all water courses of the studied area in the 19th century (Topographic map 1889, surveyed 1862-1875) and at present (Topographic map 2000-2002) showed that:

- during last 140 years the length of water courses in the studied area increased threefold and is in total 1080 km at present;
- the most intensive drainage works were conducted in the Płutnica Valley where the length of water channels increased almost seven times (Fig. 16), as well as on Dębkowskie Meadows, Bielawskie Błota raised bog and in Czarna Wda Valley (the length of water channels increased 4.3 to 5.4 times);
- during the first studied period the densest drainage network was at Karwieńskie Wetlands, where almost 11 km of drainage channels per 1 km^2 was observed; the least drained area was Bielawskie Błoto bog (1.62 km of channels/km^2);
- at present the highest density of channels and ditches occurs at Łąki Dębkowskie Meadows (21.41 km of ditches/km^2) and in the Czarna Wda Valley (18.84 km of ditches/km^2); the lowest relative number of channels is still at Bielawskie Błoto bog (Table 10).

Comparison of the length of roads located within the studied area in years 1862-1875 (Topographic map 1889) and at present (Topographic map 2000-2002) showed that:

- the total length of roads during last 140 years increased almost four times;
- the most intensive development of the communication network was observed in the region of Płutnica Valley, where in the end of the 19th century only one road joining Łebcz and Starzyński Dwór villages existed, while at present the total length of roads is more than 34 km (the length of roads increased 24 times!);
- both in the first period of studies, and at present, the best developed infrastructure of roads exists at Karwieńskie Wetlands; at present there is 5.3 km of roads per each km^2 (Table 11).

Table 10
The length of water courses in years 1862-1875 and 2000-2002

Spatial units (regions)	1862-1875		2000-2002	
	length [km]	length/km² [km/km²]	length [km]	length/km² [km/km²]
Białogóra region and Wierzchucińskie Bagno bog	49.15	3.38	180.98	12.45
Piaśnickie Meadows	23.54	4.82	72.50	14.85
Dębkowskie Meadows	53.30	3.93	290.31	21.41
Karwieńskie Wetlands and Karwia region	129.75	10.90	166.60	14.00
Czarna Wda Valley	30.59	4.38	131.62	18.84
Bielawskie Błoto raised bog	24.15	1.62	130.65	8.77
Płutnica Valley	15.57	2.09	107.58	14.45
Sum	326.04	4.39	1080.24	14.56

Table 11
Length of roads in years 1862-1875 and 2000-2002

Spatial units (regions)	1862-1875		2000-2002	
	length [km]	length/km2 [km/km2]	length [km]	length/km2 [km/km2]
Białogóra region and Wierzchucińskie Bagno bog	11.92	0.82	48.51	3.34
Piaśnickie Meadows	4.69	0.96	19.63	4.02
Dębkowskie Meadows	18.92	1.40	51.97	3.83
Karwieńskie Wetlands and Karwia region	19.67	1.65	63.12	5.30
Czarna Wda Valley	3.20	0.46	17.62	2.52
Bielawskie Błoto raised bog	15.35	1.03	51.33	3.45
Płutnica Valley	1.41	0.19	34.24	4.60
Sum	75.16	1.01	286.42	3.86

Obtained results have to be treated only as rough ones, because neither historic, nor contemporary map do not reflect the entire network of roads.

4.2.2. Contemporary flora of raised bogs and transitional mires versus flora of fens submitted to different forms of anthropic pressure

To determine influence of different forms of anthropopressure on contemporary flora in both ecological types of mires, floristic similarity of habitats, shaped by different types of human activity were studied. In the analysis, the number of records of each species in a given type of habitat was considered.

The model of flora changes of studied habitats, obtained from canonical analysis CA, considering first to fourth ordination axes, explains almost 38% of the total variation of the data (Table 12). Distribution of samples in the ordination space showed that secondary habitats formed at ecologically different types of peatbogs, subjected to the same forms of anthropopressure, show specific floristic individuality (Fig. 17). Habitats that originate from raised bogs and transitional mires are concentrated around low and medium values of the first ordination axis, while habitats located within former fens are concentrated around medium and high values of this axis. Mean values of Zarzycki indicators (Zarzycki

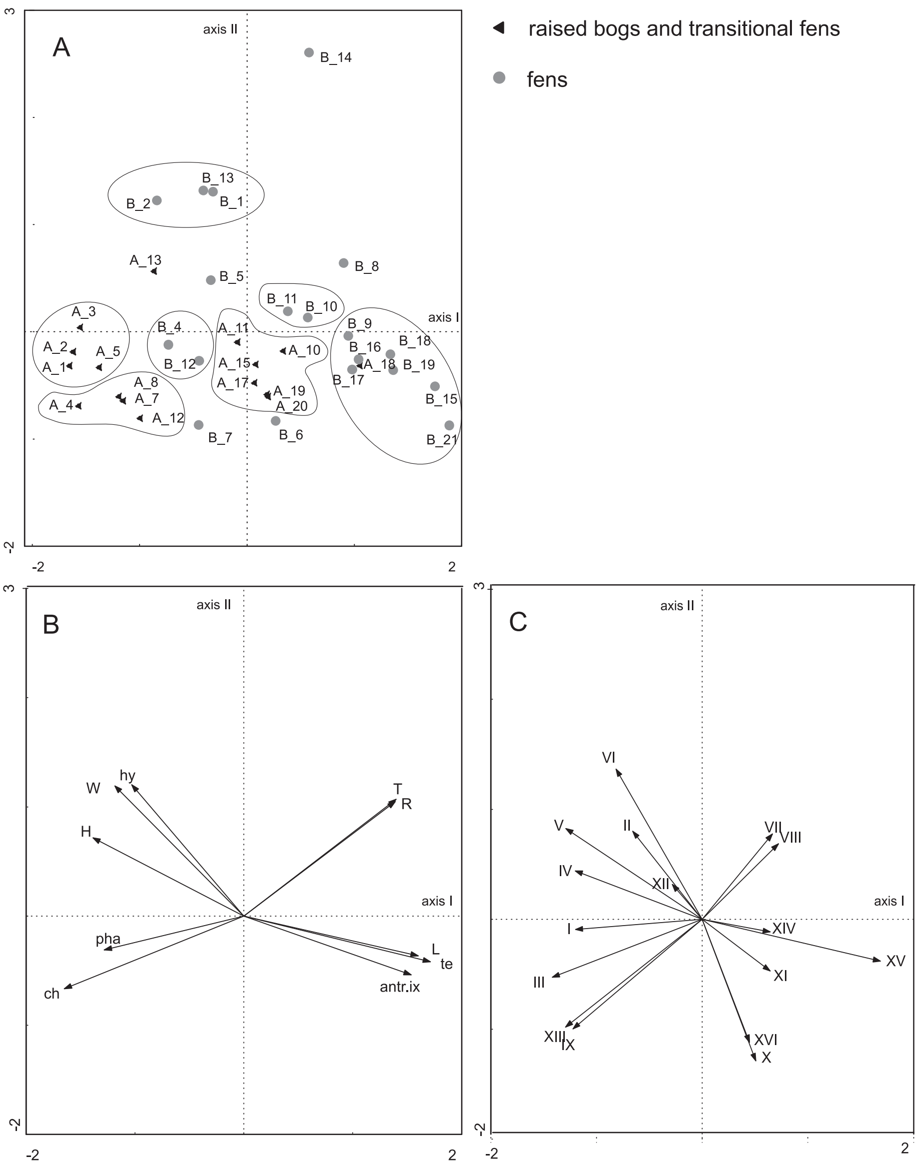


Fig. 17. The model of floristic variability of the habitats under different form of anthropic pressure (CA analysis, *inter-sample distance*, *Hill's scaling*)
A – sample plot: A_1-A_20 samples within raised bog/transitional mire habitat; B_1-B_21 – samples within fen habitat (explanations see Table 3); B – supplementary variables: Zarzycki indicators (L – light; TR – trophy; R – acidity; W – moisture; H – humus content); living forms (pha – phanerophytes; ch – chamaephytes; hy – hydro- i helophytes; te – terophytes); antr.ix – anthropophytisation index; C – supplementary variables: sociological groups (explanation see Table 2)

et al. 2002), calculated for each type of habitat, were used in the analysis as supplementary variables. Their passive projection on the diagram allowed to determine that the main gradient of variation (axis I) was associated with light availability (L), trophy, (TR), acidity

Table 12
Results of correspondent analysis CA (*inter-sample distance*, *Hill's scaling*) on floristic variability in habitats influenced by different forms of human pressure

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.500	0.366	0.313	0.265	3.814
Cumulative percentage variance of species data	13.1	22.7	30.9	37.9	
Sum of eigenvalues					3.814

Table 13
Inter-set correlation between chosen variables and ordination axes

Supplementary variables		Inter-set correlation	
Symbol	Explanation	I axis	II axis
L	light indicator	0.8148	-0.1920
TR	trophic indicator	0.7110	0.5642
R	acidity indicator	0.7073	0.5540
H	humus content indicator	-0.7059	0.3783
W	moisture indicator	-0.6035	0.6297

(R) and humus content in the substratum (H), while axis II reflects mainly the variety of moisture (W) (Table 13).

In the group of habitats associated with raised bogs and transitional mires, the following rules were stated:

- habitats formed by peat exploitation (A_2), terrestrialized pools (A_3) and shrubs (A_5) developing due to drainage, in terms of species composition of flora are close to natural habitats (A_1); their flora indicates low trophy, significant acidity of the substratum, moderate humidity and humus content; these are habitats of the highest percentage of species typical of oligotrophic waters (I) and raised bogs (II);
- similar floristic composition occurs in habitats disturbed by forestry (A_12) and in woodlands (A_4), heathlands (A_7) and burnt places (A_8) formed as a consequence of drainage; their flora closely resembles flora of natural habitats (A_1) considering indicators of trophy and acidity, but it has lower humus content and humidity of substratum; high proportion of chamaephytes as well as species typical of raised bogs (III), heathlands (IX), pine forests and acid oak forest species (XIII) are distinctive of these habitats;
- flora of habitats formed by hay meadow farming (A_10, A_11), agriculture (A_15), development of transport (A_17) and disturbance to soil cover (A_19, A_20) departs remarkably from the flora of the non-disturbed habitats, especially considering indicators of trophy and acidity, which reach much higher values there; this group is internally diverse in respect of the gradient of humidity, humus content and the percentage of anthropophytes; sociological structure of flora of these habitats is distinguished by high proportion of sandy grassland species (X) and taxa of a wide phytosociological scale (XVI);
- flora of drainage ditches and their embankments (A_13) is characterised by a significant proportion of hydro- and helophytes (HY), including species of water habitats (II), sedges and rushes (V, VI) and species typical of fens (IV); mean values of Zarzycki indicators showed their relatively high trophy and acidity;

- waste dumps (A_18) do not show any relation to the rest of habitats formed in raised bogs and transitional mires, but highly resemble disturbed habitats of fens; flora of waste dumps is characterised by very low moisture of substratum, high trophy and acidity, high values of light index; high proportion of terophytes, species of synanthropic habitats (XV) and high values of anthropophytisation index are also distinctive.

Considering habitats of fens, it was established that:

- undisturbed habitats (B_1) as well as habitats connected with peat exploitation (B_2) and development of drainage systems (B_13) have similar flora, which shows mainly high moisture of substratum and humus content; their flora is characterised by a significant proportion of hydro- and helophytes, species typical of rushes (VI), alder forests (V), eutrophic waters (II) and fens (IV);
- lower values of the moisture indicator and of humus content are reached by shrub communities, which develop in the effect of drainage works (B_5);
- flora of forest habitats (B_4) and trees plantations (B_12) is characterised by significantly lower value of moisture index than flora of non-disturbed habitats (B_1), and considering its low mean values of trophy and acidity indices it resembles habitats of raised bogs and transitional mires;
- the lowest values of trophy and acidity indicators were noted in habitats of dry heathlands (B_7), which are closed to heathlands of oligotrophic habitats (A_7), but lower moisture of the substratum and lower humus content are the differentiating factors;
- flora of sandy grasslands (B_6), formed on most drained parts of the area, indicates moderate trophy and acidity of these habitats and very low moisture and humus content; it resembles flora of the driest habitats of raised bogs and transitional mires (A_19, A_20, A_17) in this respect as well as in its similar sociological structure;
- habitats shaped by hay meadow farming or grazing (B_10, B_11) differ, by having slightly higher trophy and acidity, from habitats of raised bogs formed by the same type of the land use (A_10, A_11); their flora is characterised by the relatively high participation of meadow species (VIII) and species of silt-covered soils (VII);
- the group of the most disturbed habitats is characterised by the lowest values in the gradient of humidity and humus content, and the highest values of light indicator; their flora has the highest anthropophytisation index, great proportion of terophytes and of synanthropic species (XV); this group consists of intensively used meadows (B_9), human settlements (B_16), roads (B_17), waste dumps (B_18), habitats with mineral disposal (B_19), arable fields (B_15) and artificial surfaces (B_21);
- habitats formed on the banks of regulated rivers (B_14), which have the greatest values of trophy and acidity of substratum and with the high index of humidity, differ significantly from other habitats.

4.2.3. Flora of sample plots and its relation to selected features of natural environment

To investigate relations between floristic composition of sample plots and features of the environment, indirect (PCA) and direct (RDA) methods of analyses were used.

The model of floristic variation of sample squares obtained from the principal component analysis PCA, considering first to fourth ordination axes, explained almost 25% of

Table 14
Results of principal component analysis PCA (*inter-sample distance*, *centre by species*) on floristic variability of sample fields

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.100	0.062	0.051	0.033	1.000
Cumulative percentage variance of species data	10.0	16.2	21.3	24.6	
Sum of all Eigenvalues					1.000

Table 15
Inter-set correlation between chosen variables and ordination axes

Supplementary variables			Inter-set correlation		
Symbol	Explanation		I axis	II axis	III axis
n.sp	number of species		-0.9693	0.1205	0.1531
n.K	number of kenophytes		-0.5052	0.2037	0.5844
%A	percentage of archaeophytes		0.0275	0.1442	0.7503
%K	percentage of kenophytes		-0.0834	0.2147	0.6340
%bog	percentage of bog/transition mire area		0.0565	0.5586	-0.1503
R	Zarzycki indicators	acidity	-0.0423	-0.8020	0.1983
TR		trophic	0.0499	-0.8024	0.1808
W		moisture	-0.1032	-0.6134	-0.5256
H		humus content	-0.1075	-0.3442	-0.7107
L		light	0.1686	-0.1400	0.7208
mead+past	forms of human pressure	hay-meadow farming & grazing	-0.6469	-0.3435	0.1773
drain		creating of drainage system	-0.7431	-0.1991	0.1477
transp		transport	-0.6415	0.2377	0.0718
I	percentage of sociological groups (see Table 2)		0.2471	0.5209	-0.1395
II			-0.1936	-0.5060	0.0807
III			0.1767	0.6223	-0.2645
IV			-0.2715	0.0933	-0.5280
V			-0.2674	-0.3574	-0.6087
XIII			-0.0159	0.7146	-0.4260
XV			0.1148	0.0656	0.7057
hy	percentage of hydro- and helophytes		-0.0582	-0.7100	-0.1997
te	percentage of terophytes		-0.0212	0.2030	0.8186
forest	percentage of the forest area		-0.0220	0.5634	-0.3075
agr	percentage of the agricultural land area		-0.0721	-0.6177	0.1133
w1	percentage of classes of the age of disturbances - area disturbed since 1862-1875		0.1003	-0.5133	0.2737
w4	percentage of classes of the age of disturbances - area disturbed since 1996-1997		0.0598	0.7094	-0.0208

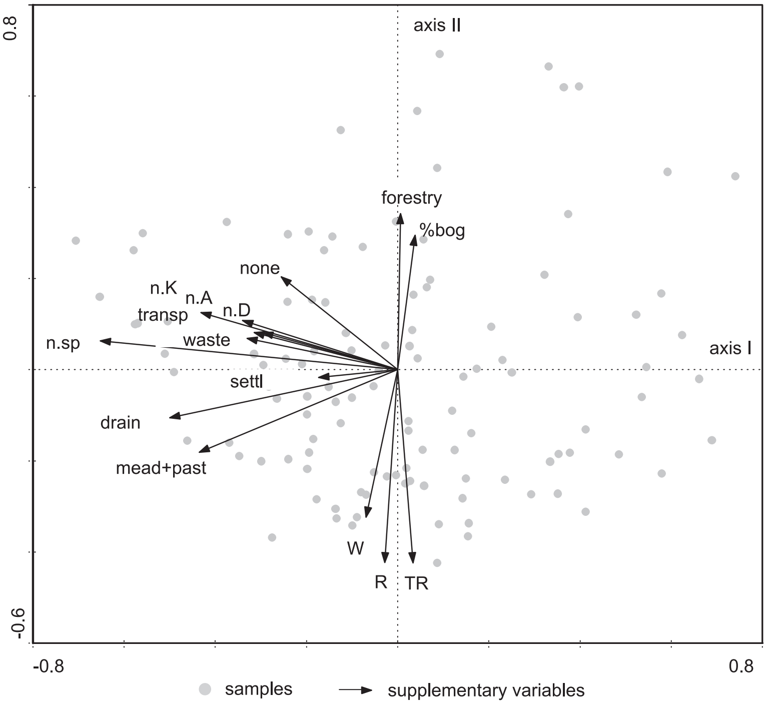


Fig. 18. Model of floristic variability of sample plots (PCA analysis, *inter sample distances, centre by species*) displaying two first ordination axes
Arrows represent supplementary variables: n.sp – number of species; forms of anthropic pressure (transp – transport; waste – waste disposal; settl – settlement; drain – creating and conservation of drainage system; mead+past – hay-meadow farming and grazing; none – no anthropic pressure); geographic-historical groups (n.A – number of archaeophytes; n.K – number of kenophytes; n.D – number of diaphytes); Zarzycki indicators (W – soil moisture; R – acidity; TR – trophy); %bog – percentage of raised bog/transitional mire habitat

the total variation in the data set (Table 14). Eigenvalues of the axes showed that the first three ordination axes had the greatest input in the explaining of variation in the analysed data set. Based on that, and by including supplementary variables into the model, it was revealed that the most important features which distinguish the flora of squares are: floristic richness (I axis), indicators of acidity and trophy of substratum (II axis), proportion of terophytes, archaeophytes and indicators of light and humus content (III axis) (Table 15).

The following relations between particular variables were stated (Table 16, Fig. 18):

- the number of species is positively correlated with the intensity of such forms of anthropic pressure as: creating the network of drainage channels, hay meadow farming and grazing, transport and waste discharge;
- proportion of raised bog species (III), oligotrophic water species (I) and heathlands species (IX) is positively correlated with the area covered by raised bogs and transitional mires and with the proportion of the post-exploitation areas;
- proportion of species typical of raised bogs (III), oligotrophic waters (I), heathlands (IX) and pine and acid oak forests (XIII) is the highest in squares with relatively recent disturbances, i.e. disturbed between 1964 and 1997 (w4); at the same time the propor-

Table 16
Correlation between chosen variables (PCA analysis)

Variable 1	Variable 2	Correlation coefficient (r)
Number of species	transport*	0.6851
Number of species	hay-meadow farming and grazing*	0.6038
Number of species	creating of drainage system*	0.7050
Number of species	waste disposal*	0.5620
Number of diaphytes	waste disposal*	0.5022
Number of kenophytes	waste disposal*	0.5152
Number of kenophytes	settlement*	0.5682
Percentage of kenophytes	built-up area**	0.5471
Percentage of kenophytes	roads length index	0.5423
Percentage of kenophytes	H	-0.5675
Percentage of kenophytes	W	-0.5438
Percentage of archaeophytes	L	0.6737
Percentage of archaeophytes	H	-0.7301
Percentage of archaeophytes	W	-0.6282
I	%bog	0.6183
I	post-exploitation area**	0.5868
I	w4	0.5592
III	%bog	0.7238
III	post-exploitation area**	0.6709
III	w1	-0.5035
III	w4	0.6966
IX	%bog	0.5862
IX	post-exploitation area**	0.5700
IX	w1	-0.5251
IX	w4	0.5710
XIII	w4	0.5138
Percentage of terophytes	L	0.7699
Percentage of terophytes	H	0.7699
Percentage of terophytes	W	-0.6686
Percentage of helo- and hydrophytes	TR	0.5612
Percentage of helo- and hydrophytes	R	0.6107
Percentage of chamaephytes	%bog	0.6125
Percentage of chamaephytes	post-exploitation area**	0.6730
%bog	no signs of disturbances**	0.5598
%bog	post-exploitation area with shrubs**	0.5315
%bog	other disturbances**	0.5249
%bog	w4	0.7780

* - number of relevés made in habitats influenced by given form of human pressure; **percentage of land cover classes area; I-XIII – percentage of sociological groups (see Table 2); H, W, L, R, TR – Zarzycki indicators, w1 - percentage area disturbed since 1862-1875; w4 - percentage area disturbed since 1996-1997; %bog – percentage of raised bog/transition mire habitat

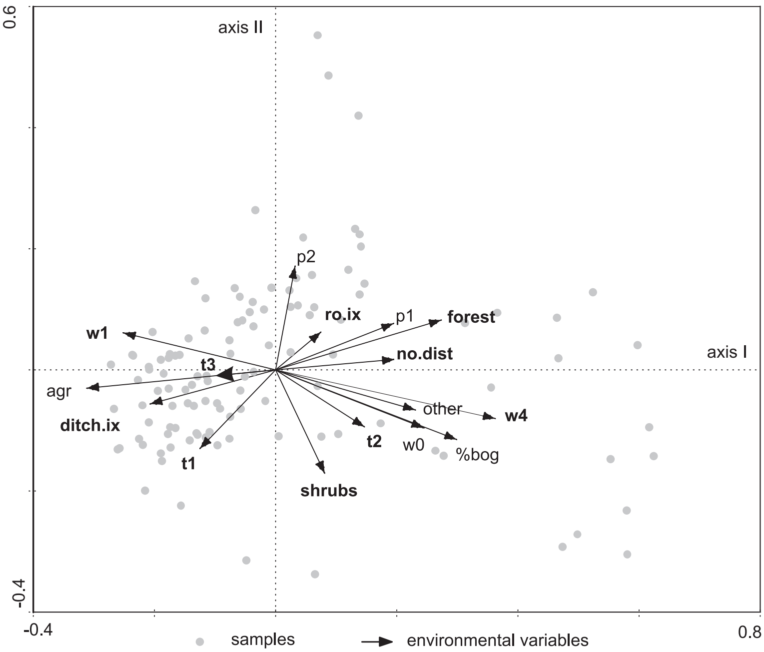


Fig. 19. Sample ordination plot (RDA analysis, *inter-sample distances*, *centre by species*). The statistically significant variables are bold (see Table 30)
Environmental variables – natural: %bog – percentage of raised bog/transitional mire habitat; geological deposits (t1 – peat; t2 – peat on loam, clay or gyttja; t3 – peat on sand or sand with humus; p1 – sand; p2 – sand with humus). Environmental variables – anthropogenic: percentage of land cover class area (no.dist – no disturbances; agr – agricultural land; other – other disturbances); percentage of classes of the age of disturbances (w0 – no disturbances; w1 – area disturbed since 1862-1875; w4 – area disturbed since 1996-1997); ro.ix – roads' length index; ditch.ix – ditches' length index

tion of raised bog species and heathlands species is negatively correlated with the area with oldest disturbances;
- proportion of kenophytes in flora is positively correlated with the area of human settlements and the length of roads; kenophytes and archaeophytes inhabit squares of a relatively low moisture and humus content, while archaeophytes require high light availability; the number of kenophytes and diaphytes is positively correlated with the intensity of waste disposing;
- the greatest proportion of terophytes in flora was recorded in squares of a relatively low moisture, low humus content and high values of light indicator; hydro- and helophytes prefer habitats of high trophy and acidity, while chamaephytes are associated with raised bog habitats, especially with post-exploited areas;
- habitats of raised bogs are distinguished by a relatively large coverage of areas with no signs of disturbance, post-exploitation areas with shrubs, or "other disturbances" (connected mainly with extensive fires occurring in the effect of desiccation of the area);
- positive correlation between the area of raised bogs and the highest age class of disturbances indicates that these habitats underwent anthropogenic change relatively late.

The model of variation of flora of studied squares (Fig. 19) obtained from the RDA analysis explains almost 27% of the total variation in the dataset (Table 17). First four canonical

Table 17
Results of redundancy analysis RDA (*inter-sample distance*, *centre by species*)
on floristic variability of sample plots

Axes	I	II	III	IV	Total inertia
Eigenvalues	0.050	0.042	0.024	0.021	1.000
Species-environment correlations	0.906	0.752	0.715	0.824	
Cumulative percentage variance of species data	5.0	9.1	11.6	13.6	
Cumulative percentage variance of species-environment relation	18.4	34.0	43.0	50.8	
Sum of all Eigenvalues	1.000				
Sum of all canonical Eigenvalues	0.269				

Table 18
Results of Monte Carlo test on first axis and on trace, as well as on environmental variables

Item tested		F	p	Variance explained [%]	
I axis		4.844	0.002	5.0	
Trace		1.627	0.002	26.9	
Variables	w4	4.706	0.002	4	*Conditional effect (Lambda A)*
	t1	2.621	0.002	2	
	forest*	2.462	0.002	2	
	ro.ix	1.898	0.006	2	
	w1	1.680	0.006	1	
	ditch.ix	1.634	0.012	1	
	t2	1.657	0.002	1	
	shrubs*	1.516	0.032	1	
	no signs of disturbances*	1.547	0.014	1	
	t3	1.437	0.022	1	

* - percentage of land cover classes area; w1 - percentage of the area disturbed since 1862-1875; w4 - percentage of the area disturbed since 1996-1997; ro.ix - length of roads per 1 km^2; ditch.ix – length of ditches per 1 km^2; t1 – percentage of peat deposits; t2 - percentage of peat on loam, clay or gyttja deposits; t3 – percentage of peat on sand or sand with humus deposits

axes, with very high species-environment correlation, explain jointly 13.6% of the variation. Statistical significance of the model and of the first canonical axis was confirmed by the Monte Carlo test (Table 18). In the procedure of forward selection of variables it was established that the most important environmental factors included in the analysis were: the age of disturbances, in particular – the coverage of the class of the most recent disturbances (w4), the type of geological deposits – coverage of peat (t1), coverage of forests and the length of roads per 1 km^2 (ro.ix).

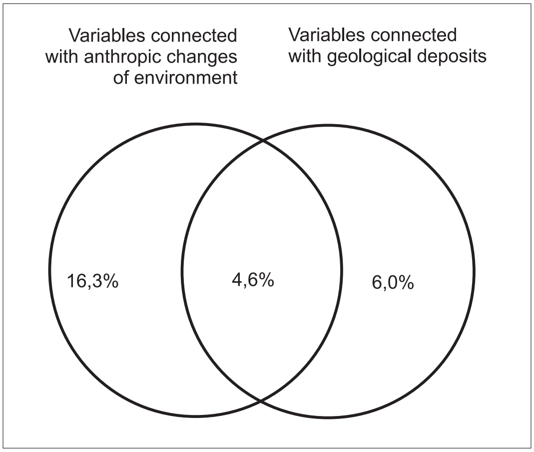


Fig. 20. Variance partitioning based on RDA analysis results

In the effect of the procedure of variance partitioning, performed on the basis of RDA, it was stated that analysed anthropogenic factors have greater explanatory power than factors connected with the geological character of the substratum. The group of variables of an anthropogenic character, which includes the percentage of the land cover classes, the index of roads' length, the length of drainage channels and the age of disturbances, jointly explains 16.3% of the total variation. Environmental variables, connected with the type of substratum (i.e. the coverage of raised bogs and the type of geological deposits) explain only 6% of variation. It is not possible to determine which environmental factors are responsible for the remaining 4.6% of variation in the studied data set (Fig. 20).

4.2.4. Contemporary flora as an indicator of habitat changes

In the analysis aimed at identification of the best preserved and the most disturbed fragments of the studied area, it was assumed that the changes in the qualitative and quantitative structure of flora may be treated as an indicator of habitat transformation due to anthropopressure. The analysis covered the spatial diversity of such features of contemporary flora as: enrichment in synanthropic species, terophytes or anthropophytes, and values of trophy, acidity, light, humidity and humus content indicators (Figs 21-28).

Spatial differentiation of number of synanthropic species, terophytes and anthropophytes in the studied area (Figs 21-23) indicate that these taxa are concentrated mainly around human settlements, especially in the region of Dębki and Karwia villages. In the remaining area these species were recorded in lower numbers, and almost complete lack of their localities within raised bogs and transitional mires was observed.

Mean values of trophy and acidity indicators in the research area reflect variation of studied habitats from oligo- to eutrophic (1.7<TR<4.8) and from strongly acidic to neutral/alkaline (1.8<R<4.6). Maps of spatial variation of mentioned indicators reflect the fact that oligotrophic and highly acidic character of substratum was preserved only in the central part of the Bielawskie Błoto raised bog, while the two remaining bogs as well as the margin of the Bielawskie Błoto have an increased trophy and acidity (Figs 24, 25). The most probable reason for these disturbances is agriculture use of the area (Budyś 2005).

The light indicator in the studied area varies between 2.7 to 4.9 (moderate shade/half-shadow – full light) and is associated with the presence of forests and shrubs (Fig. 26). It should be emphasised that areas where the mean value of L indicator shows moderate shade or half-shadow (L<3.5), have a very low coverage in the studied area (ca 3%), while the coverage of forests and shrubs is at present higher than 22%. The reason is probably the fact that as little as 4% of the area covered by forest and shrub communities can be considered as relatively old forests (more than 100 years), and more than 60% are communities younger than 40 years. Author's own observation demonstrated that in the youngest forest and shrub phytocenoses the herbaceous layer did not undergo total transformation, and some remaining species of peatbog, heathland and meadow flora have influence on relatively high mean value of the light indicator.

The map of spatial diversity of the humus content indicator showed that soils rich in organic matter are at present concentrated within raised peatbogs, as well as in the valleys of Piaśnica, Białogórska Struga and Czarna Wda rivers (Fig. 27). On the map there is a distinctive area of high values of H indicator, located near the settlement of Szary Dwór, which is probably the remain of the Odargowskie Mire (see Graebner 1895). Fragments of the area poor in humus (H<2) are located in the region of Łąki Dębkowskie Meadows, Karwieńskie Wetlands and in the neighbourhood of Ostrowska Moraine and Sławoszyńska Moraine. Drainage and agricultural use of mires caused decession of the thick layer of humus in the mineral-organic marginal part of researched area. Decrease of humus content in the centre of the studied area, e.g. in the region of Karwieńskie Błota village, is undoubtedly the effect of strong and long-term anthropic pressure. This area has the longest history of land use, and has been subjected to drainage works since 16th century.

The analysis of spatial distribution of mean values of the humidity index showed diversity of studied habitats from dry/fresh to wet ones (2.5<W<5.3) (Fig. 28). Habitats of the relatively highest moisture are located near Białogórski Channel, at Wierzchucińskie Bagno bog, in the eastern part of Bielawskie Błoto bog and in the Czarna Wda Valley. Parts of the area of low moisture values are located mainly in the region of Dębkowskie Meadows, Karwieńskie Wetlands and at the margin of Bielawskie Błoto raised bog.

5. DISCUSSION

5.1. Symptoms of mire flora synanthropisation

The results revealed that the main symptoms of flora transformation in disturbed mires are: the regression of species sensitive to the habitat disturbances as well as the invasion of environmentally and geographically alien species. These trends of change in flora are in agreement with the scheme of synanthropisation elaborated by Faliński (1966, 1972, 1998, 2000). The theory of synanthropisation assumes that this process consists mainly of hemerophobic species extinction, hemerophilous species expansion, apophytisation and neophytisation.

5.1.1. The regression of hemerophobic species

Within Błota Przymorskie Plain at least 93 vascular plant species have become extinct during the last 198 years. Nearly half of them were characteristic of peatland complexes or inland waters. The retreat of mire species in habitats under anthropic pressure in Poland and in whole of Europe has been relatively well recognized (e.g. Czubiński *et al.* 1954; Jasnowski *et al.* 1968; Görs 1969; Herbichowa 1972, 1976; Jasnowski 1972; Olesiński & Olkowski 1976; Jasnowska & Jasnowski 1977; Jasnowski & Ilnicki 1988; Dierssen 1992; Heikkilä 1992). This process has been documented not only by floristic observation but also by paleoecological data (Jasnowski *et al.* 1968; Jasnowski 1972, 1975; Headley *et al.* 1992; Tobolski 2003), which shows show that severe and rapid changes in mire flora took place during the last few centuries, during the time when human management has been developing (Jasnowski *et al.* 1968; Jasnowski 1972; Headley *et al.* 1992). To some extent, flora transformation can be also considered as a natural, long term process of succession in bogs and fens, but this aspect was studied only in particular types of mires – Baltic raised bogs (Herbichowa 1998) and spring mires (Wołejko 1991).

The analysis of regression of bog flora revealed that only some hollow species (representing *Rhynchosporion albae* in the *Scheuchzerietalia palustris* order) became extinct, while all those from hummocks (from the *Oxycocco-Sphagnetea* class) persisted within the studied area for the last 200 years (Budyś 2004). The domination of hummock species in drained bogs in Denmark was pointed out by Aaby (1994). In Poland this process needs to be studied as it can give some clues as to the possibilities of the persistence of mire species in bogs submitted to anthropic pressure.

5.1.2. The expansion of hemerophilous species and neophytisation

The number of species in the flora of Polish pristine mires is estimated at 130-230 (Tołpa *et al.* 1967; Jasnowski 1972, 1975). Contemporary flora of studied peatlands is extremely rich and consists of 958 vascular plant species. The presence of alien species in disturbed mires was reported by Jasnowski *et al.* (1968), Jasnowski (1972), Dierssen (1992), Aaby (1994), Celka & Szkudlarz (2000), Załuski & Kamińska (2000) and Tomassen *et al.* (2004), among others, but there has been no systematic study regarding this problem. The results of past research suggest that the enrichment of mire flora is caused by desiccation, microclimatic changes, eutrophication or particular human activities such as transportation or mowing (Shaw & Wheeler 1992; Aaby 1994; Celka & Szkudlarz 2000; Tomassen *et al.* 2004). The present results reveal that the main forms of anthropic pressure which stimulate the increase in the number of species are: the development of drainage systems, transportation, hay-meadow farming, the use of land as pasture and waste disposal.

The most interesting aspect of mire flora enrichment is the expansion of geographically alien species. Jasnowski (1972) revealed that only five neophytes were inhabited in peatlands. Although there were 196 anthropophytes recorded in the present-day flora of the studied area, one third of them are diaphytes, which are not able to inhabit permanently in this type of habitat. Moreover, most of the alien species are classified as extremely rare or rare (frequency class I and II), except for some more common archaeophytes. On the other hand, archaeophytes are considerably less frequent in oligo- or mesohemerobic habitats than kenophytes. Such a conclusion was also reached by Jackowiak (1990), in regard to the flora of the city of Poznań. The relatively wide ecological amplitude of kenophytes is the reason for their expansiveness (Pyšek *et al*. 2003; Tokarska-Guzik 2005), whereas archaeophytes are more often attached to a segetal habitat.

The mire flora transformation should be considered in terms of spatial bearing as well. The results show that raised bog and transition mire flora are much less enriched in synanthropic species (according to sociological classification) and anthropophytes than fen flora. Moreover, the alien species within raised bogs are recorded almost entirely in anthropogenic habitats such as hard-surfaced roads. The reasons for the resistance of bog habitats to alien species expansion are not well recognized. Firstly, one can assume that the anthropic pressure in these habitats is less intensive than in fens, or that there is a lack of some forms of activity which stimulate the flora enrichment (e.g. settlement). Secondly, environmental features such as high ground water level, scarcity of nutrients and high acidity can be limiting factors for alien species, even if the bog is significantly destroyed. Cleland *et al.* (2004) recorded a positive correlation between the probability of anthropophytes settlement and floristic diversity in plant communities. They also proved that alien species are rarely able to inhabit if the bank of available nutrients is used up by resident species. These facts suggest that extremely low fertility of raised bogs and transitional mires can be the main reason which hampers the invasion of hemerophilous species.

5.2. The reasons for mire flora synanthropisation

The regression of peat-forming species results, in most cases, from the desiccation of peat (Görs 1969; Jasnowski 1972; Jasnowski *et al*. 1968; Herbichowa 1979). In Błota Przymorskie Plain the drainage was very intensive – a possible cause of the retreat of wetland species; especially since a lot of mire species became extinct after 1940, when the bulk of the drainage measures were completed.

The lowering of the ground water table in the studied area caused shrinkage of the peat layer and, locally, even its complete decay. As a result, some islands of mineral soil within the complex of organic deposits were created. Such changes in Poland were observed by Ilnicki (1965); Roguski & Bieńkiewicz (1967) and Jasnowski *et al*. (1968), among others. In Błota Przymorskie Plain the enlargement of the area of mineral or organo-mineral soils is the reason for the enrichment in mire flora in sandy grassland and heathland species and in annual species typical for synanthropic habitats.

The drainage results not only in peat humification, but stimulates secondary succession of trees and shrubs in peatlands as well (Tallis 1983; Jasnowski & Ilnicki 1988). The development of trees is a threat for peat-forming species because of competitive interaction (e.g. limitation of light) and its contribution to reducing soil moisture (Tobolski 2003). The intensive succession of forest communities was observed in the studied area in the 1950s (in Wierzchucińskie Bagno bog) and 1970s (in Bielawskie Błoto and Łebcz raised bogs), which could be the reason for the extinction of several bog species noted for the last time between 1941 and 1979 (e.g. *Scheuchzeria palustris*, *Lycopodiella inundata*, *Drosera intermedia*).

Another form of anthropic pressure which significantly modifies the environment and flora of mires is peat exploitation (Podbielkowski 1960; Tallis 1983; Aaby 1994; Celka &

Szkudlarz 2000). The main result of mining, except the obvious limitation in peat surface available for plant growth, is the instability in the hydrological regime and the development of specific microrelief with damp peat digs and desiccated embankments (Tallis 1983; Aaby 1994). If the water level in post-exploitation digs is high enough, they can form a suitable habitat for the growth of bog flora (Podbielkowski 1960; Jasnowski *et al*. 1968; Görs 1969). The depth of mining, however, has an influence on species composition in regenerating communities (Tallis 1983). The massive growth of rush species, observed in digs in the Łebcz raised bog, points out that the layer of eutrophic deposits underlying oligotrophic peat was exposed during exploitation. On the other hand, embankments of digs can play a role in the initiation of forest succession in mires. In pristine mires the settlement of trees takes place on dry hummocks, but is limited by seasonal fluctuations in the water table level (Godwin & Bharucha 1932; Tallis 1983). In post-exploited areas dried dikes are often overgrown by birch or pine trees. Such a process is observed for instance in the western part of the Bielawskie Błoto raised bog.

The greater part of the studied area, especially within the fen habitat, is nowadays turned into hay-meadows, pastures or arable fields, which significantly affects the floristic composition. Mowing and pasturing have a different influence on raised bog habitat and fen habitat. It was proven by Heathwaite *et al*. (1993) that, from a phytocoenotical point of view, there is no difference between raised bogs submitted to hay-meadow farming and mineral habitats treated in the same way. The results of the present research are similar, although there were some remnants of the bog flora (e.g. individuals of *Erica tetralix* or *Drosera rotundifolia*) found within meadows established in the bog habitat. In the fen habitat mowing and pasturing leads to the domination of meadow species, especially grasses (Pearsall 1956), but such treatment also allows some fen species or sedge rush species to persist. Mowing is particularly needed in fen communities when the ground water table level is lowered, because it prevents tree and shrub establishment (Wheeler 1988; Fojt 1992a; Shaw & Wheeler 1992). Agricultural use of peatlands completely changes the flora, regardless of the ecological type of mire. Jasnowski *et al*. (1968) pointed out that in ploughed wetlands, where the peat layer has decayed, secondary vegetation has no features referring to the primary type of habitat. The present research is in agreement with their findings.

The next serious threat for the persistence of raised bog and poor fen flora is eutrophication. This phenomenon is particularly important in Western Europe, where ground waters are supplied with significant amounts of nitrogen and phosphorous compounds through rainfall (Press *et al*. 1986; Aerts *et al*. 1992; Fojt 1992b; Twenhöwen 1992; Aaby 1994; Tomassen *et al*. 2004). The spatial differentiation of trophic indicators in the studied area shows that eutrophic habitats are rather rare and scattered, and generally the trophic gradient between bogs and fens is still distinct. Points with enormously high mean values of trophic indicators were noted mainly within anthropogenic habitats, like farmyards and disposal sites. Moreover, in raised bog habitats such places are observed in the case of agricultural use (Budyś 2005). Eutrophication can also be a problem in bog pools, which are resting and feeding places for migrating birds, e.g. in the Bielawskie Błoto raised bog. Such a case was mentioned by Tomassen *et al*. (2004), who studied the expansion of *Molinia* and *Betula* in an Irish peat bog where bird droppings caused enlarged nutrients supplies.

The most sweeping changes in mire flora, however, are caused by human settlement. The studied site is located in a coastal zone, so many villages have become tourist resorts and relatively big area of wetlands has been colonized, for instance near the villages of Karwieńskie Wetlands and Karwia. In these places, where the peatland habitat has been destroyed, mire flora has survived only in small patches, e.g. in drainage ditches. Moreover, settlement is the most important factor which stimulates the expansion of geographically alien species, especially kenophytes in disturbed mires.

5.3. The direction and progress of synanthropic changes

The analysis of successive stages in studied peatland flora synanthropisation revealed that the main trends of change are: the increase of floristic diversity; the substitution of mire species with species of wide sociological amplitude, synanthropic species, meadow species and forest species; the increasing role of terophytes and phanerophytes; and the increase of the proportion of anthropophytes. The obtained results confirm the theory of Faliński (1972), which says that anthropogenic changes in flora proceed towards eurytopisation, allochtonisation and complication. According to Faliński (1972), the decline of primary features of plant cover, which were prescribed by floristic and climatic history, is the consequence of synanthropisation. The flora of Błota Przymorskie Plain, despite far reaching qualitative and quantitative changes, is still connected, to some degree, with the primary type of habitat. Even though the bogs and fen habitats in the researched area were submitted to analogous forms of pressure, their flora is distinct, for instance with respect to mean values of ecological indicators. The differences in flora of these two types of mire are lost only in terms of such drastic forms of anthropopressure as waste disposal. Therefore, the hypothesis that the extent and symptoms of flora synanthropisation in peatlands depend both on the form of human pressure and ecological type of mire is proven.

From a geobotanical point of view, the studied area still has some features typical to Polish coastal mires (Czubiński 1950). The coexistence of Atlantic and boreal species in contemporary flora can still be observed. However, as a result of anthropogenic changes in habitats (e.g. the development of dry heathlands or sandy grasslands), the proportion between these two groups of species has moved towards Atlantic range species (Budyś 2006).

6. THE MAIN FINDINGS AND CONCLUSIONS

During the past 198 years in the flora of vascular plants of the Błota Przymorskie Plain and Płutnica Valley 958 taxa were listed. The contemporary flora of studied peatlands is extremely rich and consists of 808 vascular plant species. The main forms of anthropic pressure which stimulate the increase in the number of species are: the development of drainage systems, transportation, hay-meadow farming, the use of land as pasture and waste disposal.

Among 93 species, which became locally extinct, species associated with aquatic habitats and habitats of high groundwater level comprise 49%. The greatest losses in flora were stated after 1940, when the bulk of the drainage measures were completed.

The most important trends of changes in flora of disturbed mires, apart from extinction of hemerophobic species, are: the increase of floristic diversity; the substitution of mire species with species of wide sociological amplitude, synanthropic species, meadow species and forest species; the increasing role of terophytes and phanerophytes; and the increase of the proportion of anthropophytes.

Even though the bogs and fen habitats in the researched area were submitted to analogous forms of pressure, their flora is distinct, for instance with respect to acidity and trophy of substratum.

Among analysed environmental factors, which influenced the spatial differentiation of contemporary flora, the greater explanatory power have anthropogenic variables (the percentage of the land cover classes, the length of roads, the length of drainage channels and the age of disturbances) than variables connected with the geological character of the substratum (the coverage of raised bogs and the type of geological deposits).

The results of the presented research lead to the following conclusions: (1) anthropic pressure in coastal mires leads to ahemerobic habitat disappearance, oligohemerobic habitat fragmentation and the development of habitats with a higher degree of hemeroby – as an effect of this process a mosaic of secondary habitats develops and floristic diversity increases; (2) the advancement of synanthropisation processes depends both on the form and intensity of anthropic pressure and on the former ecological type of mire, while bog habitats are more resistant to alien species expansion than fens; (3) despite deep flora disturbances such as eurytopisation or allochtonisation, the contemporary flora of coastal peatlands still has some characteristic features connected with geology, ecological differentiation and geobotanical location; (4) flora synanthropisation process on disturbed mires still needs to be studied.

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8. SYNANTROPIZACJA FLORY ROŚLIN NACZYNIOWYCH TORFOWISK W STREFIE PRZYMORSKIEJ (POBRZEŻE KASZUBSKIE, POLSKA PÓŁNOCNA) – ZAKRES, PRZYCZYNY I UWARUNKOWANIA PRZESTRZENNE (streszczenie)

Cel i teren badań. Celem pracy jest rozpoznanie zakresu antropogenicznych przemian flory na zróżnicowanych ekologicznie siedliskach torfowych strefy przymorskiej oraz zbadanie przestrzennych uwarunkowań i przyczyn tego procesu. Celem szczegółowym pracy jest: (1) ustalenie składu gatunkowego historycznej i współczesnej flory roślin naczyniowych na torfowiskach reprezentatywnych dla obszaru przymorskiego; (2) określenie przejawów, etapów i specyfiki transformacji flory na zaburzonych siedliskach torfowych; (3) rozpoznanie tendencji dynamicznych wybranych składników flory; (4) prześledzenie głównych etapów antropogenicznych zmian środowiska przyjętego terenu badań; (5) ustalenie zależności między jakościowym, ilościowym i przestrzennym zróżnicowaniem flory a formami

antropogenicznych oddziaływań i stopniem przeobrażenia środowiska przyrodniczego oraz wskazanie najważniejszych czynników kształtujących strukturę flory współczesnej zmienionych siedlisk torfowych.

Do badań wytypowano wycinek pasa zatorfionych obniżeń, który rozciąga się między mierzejami a wysoczyznami morenowymi wzdłuż całego wybrzeża Bałtyku (KONDRACKI 2001). Teren ten obejmuje kompleks dominujących przestrzennie torfowisk niskich oraz trzech torfowisk wysokich typu bałtyckiego (Fig. 1). Pod względem uwarunkowań geomorfologicznych, cech klimatycznych oraz typologicznego zróżnicowania torfowisk wybrany fragment Pobrzeża Kaszubskiego jest reprezentatywny co najmniej dla wschodniego odcinka wybrzeża Bałtyku. Ze względu na długotrwałą, bezpośrednią lub pośrednią antropopresję, teren ten współcześnie stanowi swoistą mozaikę siedlisk zróżnicowanych pod względem stopnia przekształcenia i sposobu użytkowania. Spośród innych podobnych kompleksów obszar ten wyróżnia się stosunkowo bogatą, choć niepełną dokumentacją florystyczną pochodzącą z wieków XIX i XX. Według przyjętej w niniejszym opracowaniu regionalizacji AUGUSTOWSKIEGO (1969, 1974) badany teren jest położony w obrębie Pobrzeża Kaszubskiego i obejmuje Równinę Błot Przymorskich oraz fragment Pradoliny Płutnicy (Fig. 2).

Materiał i metody. Współczesny skład flory naczyniowej został ustalony na podstawie własnych badań terenowych prowadzonych w sezonach wegetacyjnych 2000-2004, uzupełnionych o dane z lat 1997-2002 pochodzące z opracowań innych autorów. Badany obszar został podzielony na 122 pola podstawowe (stanowiska) – kwadraty o powierzchni 1 km^2, które zostały wydzielone w obrębie sieci ATPOL. W każdym kwadracie badań wykonano zdjęcia florystyczne w taki sposób, aby reprezentowały wszystkie możliwe typy użytkowania terenu oraz różne typy fitocenoz. Aktualna lista roślin naczyniowych uzupełniona została o wszystkie dane florystyczne pochodzące z wcześniejszych badań. W historii badań florystycznych umownie wydzielono pięć okresów obejmujących następujące lata: I – 1809-1896, II – 1897-1940, III – 1941-1979, IV – 1980-1996, V – 1997-2004. Baza danych liczy łącznie 81019 dat florystycznych, z czego do flory współczesnej odnosi się 74425 dat; na kartotekę historyczną składają się 6594 daty. Gatunki w bazie zostały scharakteryzowane pod względem frekwencji, przynależności fitosocjologicznej, przynależności do grup geograficzno-historycznych oraz form życiowych. Dynamikę poszczególnych taksonów we florze współczesnej określono na podstawie wskaźnika apofityzmu (I_{ap}) oraz wskaźnika naturalizacji (I_{nat}). Badane siedliska sklasyfikowano pod względem stopnia hemerobii oraz ze względu na genezę i sposób użytkowania.

Analizę obecnego stanu oraz rekonstrukcję przemian wybranych elementów środowiska przyrodniczego przeprowadzono wykorzystując mapy topograficzne, mapy utworów powierzchniowych, szkice sytuacyjne z dokumentacji geologicznych złóż torfu oraz archiwalne i aktualne zdjęcia lotnicze. Na podstawie tych materiałów stworzono m.in. mapy klas pokrycia terenu w czterech przedziałach czasowych, mapy historycznej sieci dróg i cieków oraz syntetyczną mapę wieku zaburzeń. Na podstawie wybranych cech flory w punktach spisów florystycznych opracowano mapy wskaźnikowe obrazujące zaburzenia flory i siedliska, np. mapę liczby antropofitów, mapy średnich wartości wskaźników Zarzyckiego dla trofizmu, wilgotności i zawartości materii organicznej w glebie.

Zależności między zróżnicowaniem flory a wybranymi cechami środowiska zostały zbadane z wykorzystaniem analiz wielowymiarowych (DCA, PCA, RDA, CA) i technik GIS.

Wyniki

Zakres przemian flory i cechy flory współczesnej. W ciągu ostatnich 198 lat we florze naczyniowej Równiny Błot Przymorskich i Pradoliny Płutnicy stwierdzono łącznie 958 taksonów, natomiast aktualną florę badanego terenu tworzy 808 taksonów. Flora obszaru siedliskowego torfowisk wysokich i przejściowych liczy 570 taksonów, a flora byłych torfowisk niskich – 927, z czego we florze współczesnej odnotowano odpowiednio 459 i 792 taksony roślin naczyniowych.

Spośród 150 gatunków, których współcześnie nie odnaleziono na badanym obszarze 93 można uznać za wymarłe (nie notowane co najmniej od roku 1979). Pozostałe 57 gatunków nieodnalezionych ma status niepewny (gatunki pospolite prawdopodobnie przeoczone w tracie obecnych badań, gatunki prawdopodobnie błędnie podane w trakcie poprzednich badań oraz gatunki, które nie były trwale zadomowione we florze). Wśród gatunków lokalnie wymarłych znaczący udział mają taksony o nieokreślonej przynależności fitosocjologicznej, wodne, torfowiskowe oraz łąk wilgotnych. Gatunki związane z siedliskami wodnymi oraz cechującymi się wysokim poziomem wód gruntowych stanowią 49% wszystkich wymarłych.

Stwierdzono następujące prawidłowości: w grupie gatunków wód oligo- i mezotroficznych dużo większe straty zanotowano we florze siedlisk skąpożywnych (klasa *Littorelletea* – 7 gatunków) niż umiarkowanie zasobnych (klasa *Utricularietea* – 1); wśród gatunków wód eutroficznych i źródlisk straty dotyczą wyłącznie przedstawicieli wodnych makrofitów (klasa *Potametea* – 6); spośród gatunków związanych z kompleksem wysokotorfowiskowym do lokalnie wymarłych zaliczono jedynie gatunki reprezentujące rząd *Scheuchzerietalia palustris* (8), które na torfowisku wysokim są składnikami dolinek; stosunkowo największe straty we florze niskotorfowiskowej zanotowano w grupie związanej z siedliskami neutralnymi i alkalicznymi (rząd *Caricetalia davallianae* – 5); w grupach taksonów olsowych i szuwarowych stwierdzono jedynie nieznaczny spadek liczby gatunków (odpowiednio 3 i 4); zanik stanowisk terofitów wilgotnych siedlisk mineralnych i namulisk dotyczy tylko gatunków z klasy *Isoëto-Nanojuncetea* (3); lokalnie wymarłe taksony związane z łąkami wilgotnymi wywodzą się głównie ze zbiorowisk zmiennowilgotnych łąk i ziołorośli nadrzecznych (rząd *Molinietalia* – 4).

Analiza ubywania gatunków w kolejnych okresach badań wykazała, że największe straty we florze stwierdzono po roku 1940 – 63 taksony roślin naczyniowych notowano po raz ostatni w latach 1897-1940, podczas gdy w latach 1809-1896 było takich gatunków 17, a w latach 1941-1979 zanotowano po raz ostatni 12 gatunków. Wśród gatunków notowanych ostatni raz w latach 1897-1940 duży udział miały taksony wód oligo- i mezotroficznych, torfowisk, łąk wilgotnych oraz wrzosowisk, a także gatunki o szerokiej skali fitosocjologicznej.

Ze względu na brak pełnej dokumentacji flory w poszczególnych okresach badań nie jest możliwe prześledzenie etapów jej wzbogacania w gatunki obce siedliskowo i geograficznie. Zasadniczo można przyjąć, że począwszy od roku 1809 liczba gatunków roślin naczyniowych we florze terenu badań stopniowo zwiększała się. W kolejnych okresach badań zanotowano: 1809-1896 – 327 gatunków; 1897-1940 – 545; 1941-1979 – 366 (w tym okresie notowania odnoszą się jedynie do wybranych fragmentów terenu); 1980-1996 – 619; 1997-2004 – 808. Łączna liczba gatunków odnotowanych na badanym terenie stanowi 33% flory naczyniowej Polski, szacując że współcześnie liczy ona około 2980 gatunków (Mirek *et al.* 2002).

We florze współczesnej badanego terenu stwierdzono 612 spontaneofitów oraz 196 antropofitów. Wśród gatunków obcego pochodzenia przeważają diafity (76), grupa archeofitów liczy 61 gatunków, kenofitów zaś – 59. Ponad połowę taksonów wśród archeofitów stanowią rośliny bardzo rzadkie i rzadkie. W grupie diafitów i agriofitów brak jest zupełnie gatunków pospolitych i bardzo częstych. Łączny udział gatunków z I i II klasy frekwencji jest najwyższy wśród diafitów (94%), a wśród kenofitów wynosi od 62% (hemiagriofity) do 84% (epekofity).

We florze współczesnej taksony torfowiskowe s.lat. stanowią łącznie 4,7% ogółu gatunków. Wszystkie gatunki związane z wysokim poziomem wody, czyli rośliny wodne, torfowiskowe, bagienne oraz szuwarowe obejmują łącznie 15,6% flory. Największy udział we florze mają taksony o nieokreślonej przynależności fitosocjologicznej (33%). Nieco ponad 19% flory stanowią gatunki synantropijne, wśród których najliczniejsze związane są z siedliskami ruderalnymi oraz chwastami zbożowymi i okopowymi. Stosunkowo duży udział we florze mają rośliny łąkowe, przy czym znacznie liczniejsze w tej grupie są gatunki związane z siedliskami wilgotnymi (9,3% flory) niż ze świeżymi (3,2%). Znaczący udział (8,3%) mają również taksony żyznych lasów liściastych i zbiorowisk zaroślowych.

We współczesnej florze obszaru badań największy udział mają hemikryptofity (41%) oraz terofity (25%). Fanerofity, geofity oraz hydro- i helofity stanowią odpowiednio 13, 9 i 8% flory. Najmniej liczna jest grupa chamefitów, które tworzą zaledwie 4% flory. Wzbogacenie flory w gatunki reprezentujące geofity, fanerofity i terofity może być uznane za przejaw zaburzeń antropogenicznych, gdyż reprezetowane są one głównie przez taksony obce siedliskowo.

Tendencje dynamiczne wybranych grup gatunków we florze współczesnej. Tendencje dynamiczne flory współczesnej zostały scharakteryzowane na podstawie wskaźników apofityzmu (I_{ap}) oraz naturalizacji (I_{nat}).

Brak tendencji do zajmowania siedlisk silnie zmienionych ($I_{ap} = 0$) stwierdzono u 6% spontaneofitów, reprezentowanych m.in. przez gatunki charakterystyczne dla wód eutroficznych, torfowisk i kwaśnych lasów bagiennych, olsów i szuwarów oraz łąk wilgotnych. Grupa gatunków nieprzejawiających tendencji do apofityzmu cechuje się stosunkowo wysoką średnią wartością wskaźnika wilgotności i zawartości materii organicznej oraz niską wartością wskaźnika światła.

Gatunki o silnych i bardzo silnych tendencjach do zajmowania siedlisk głęboko przekształconych ($51\% \leq I_{ap}$) stanowią 7% spontaneofitów. Struktura socjologiczna tych syntaksonów wskazuje, że są one reprezentowane głównie przez taksony siedlisk synantropijnych, a zwłaszcza ruderalnych i segetalnych, muraw napiaskowych, ciepłolubnych okrajków i muraw, łąk, namulisk i wilgotnych siedlisk mineralnych oraz gatunki o nieokreślonej przynależności fitosocjologicznej. Do spontaneofitów, które w największym stopniu przywiązane są do siedlisk eu- i polyhemerobnych należą m.in. *Aethusa cynapium*, *Arctium minus*, *Erodium cicutarium*, *Juncus compressus*, *Melilotus alba* oraz *Trifolium arvense*. Średnie wartości liczb wskaźnikowych Zarzyckiego dla wilgotności, trofii i zawartości materii organicznej w tych grupach są stosunkowo niskie, natomiast wskaźnik światła jest relatywnie wysoki.

Spośród antropofitów 18% wykazuje słabe zdolności do zajmowania siedlisk oligo- i mezohemerobnych ($1\% \leq I_{nat} \leq 25\%$); przeważają wśród nich archeofity. Taksony o silnych i bardzo silnych tendencjach do naturalizacji ($51\% \leq I_{nat}$), stanowiące 9% wszystkich roślin obcego pochodzenia, rekrutują się w większości z kenofitów. Najsilniejsze tendencje do zajmowania siedlisk oligo- i mezohemerobnych (76%≤I_{nat}) wykazuje pięć gatunków kenofitów: *Elodea canadensis*, *Lolium multiflorum*, *Padus serotina*, *Picea abies* oraz *Pyrus communis*.

Przyczyny przemian flory. Na podstawie analizy archiwalnych i współczesnych map topograficznych, zdjęć lotniczych oraz wybranych pozycji literatury stwierdzono, że głównymi formami antropopresji, które wpłynęły na stan środowiska przyrodniczego badanego obszaru są: melioracje odwadniające i regulacja rzek, użytkowanie łąkarskie, pastwiskowe, rolnicze, eksploatacja torfu, osadnictwo, budowa sieci dróg i transport, gospodarka leśna oraz zaśmiecanie. Nasilająca się antropopresja znalazła odbicie w następujących po sobie zmianach struktury użytkowania terenu. Zmiany te przejawiały się głównie stopniowym zmniejszaniem się powierzchni o najmniejszym stopniu zaburzenia (w latach 1862-1875 stanowiącej 43% powierzchni terenu, a obecnie zaledwie 4%) na rzecz terenów użytkowanych rolniczo (współcześnie 65% powierzchni) oraz zajętych przez zbiorowiska zaroślowe i leśne (22% powierzchni). Na podstawie map klas pokrycia terenu dla czterech kolejnych przedziałów czasowych wykonano syntetyczną mapę wieku zaburzeń. Wynika z niej, że ponad 80% badanego terenu była zaburzona w widoczny sposób już w początkowych okresach badawczych, tj. między latami 1862 i 1939. Obszary zaburzone w późniejszych latach to w przewadze niewielkie powierzchnie zlokalizowane na torfowiskach wysokich i przejściowych lub na ich obrzeżach. Część z nich zamieniono po roku 1939 na użytki rolne, a część została opanowana przez zarośla i lasy.

Analiza związku między przestrzennym zróżnicowaniem flory a oddziaływaniem człowieka i cechami środowiska przyrodniczego, przeprowadzona na podstawie zastosowanych metod wielowymiarowych i analiz przestrzennych, wskazuje na następujące prawidłowości:

- W gradiencie typologicznym siedlisk torfowych flora wykazuje w dalszym ciągu znaczne różnice, związane przede wszystkim z kwasowością i zasobnością siedlisk. Pewna odrębność florystyczna siedlisk wtórnych, ukształtowanych na różnych ekologicznych typach torfowisk, zostaje zachowana nawet wówczas, gdy siedliska poddane są zbliżonym formom antropopresji.
- Na obszarze siedliskowym torfowisk wysokich i przejściowych najmniej drastyczne zmiany we florze powodują eksploatacja torfu i umiarkowane osuszenie podłoża; znaczna modyfikacja flory została stwierdzona na obszarach zaburzonych przez silne odwodnienie, użytkowanie łąkarskie, rolnictwo, transport i budowę sieci rowów odwadniających, natomiast najbardziej radykalne zmiany jakościowe flory następują w miejscach zaśmiecanych.
- W granicach obszaru siedliskowego torfowisk niskich florystycznie najbardziej zbliżone do siedlisk niezaburzonych są tereny kształtowane przez eksploatację torfu i budowę sieci rowów. Znaczną modyfikację flory powoduje silne osuszenie, prowadzące do odsłonięcia podtorfowych utworów mineralnych i gospodarka leśna, natomiast najsilniejszą przebudowę flory zanotowano na siedliskach zaburzonych przez intensywne użytkowanie łąkarskie, rolnictwo, rozwój osadnictwa i transportu, zaśmiecanie, nawożenie obcego substratu i tworzenie sztucznych podłoży.
- Wśród zbadanych zmiennych środowiskowych największy wpływ na przestrzenne zróżnicowanie flory mają: wiek antropogenicznych zaburzeń, charakter utworów powierzchniowych (areał torfu), udział powierzchniowy obszarów leśnych oraz długość dróg na jednostkę powierzchni. Ustalono, że jakość flory współczesnej jest w większym stopniu

uzależniona od zmiennych związanych ze strukturą użytkowania terenu niż z uwarunkowaniami siedliskowymi wyrażonymi jako geologiczny charakter utworów powierzchniowych.

- Bogactwo florystyczne jest związane z nasileniem takich form antropopresji jak budowa sieci rowów, łąkarstwo, transport i zaśmiecanie.
- Udział gatunków charakterystycznych dla torfowisk wysokich jest pozytywnie związany z areałem otwartych obszarów poeksploatacyjnych.
- Poziom synantropizacji zależy od formy i natężenia antropopresji – ustalono pozytywny związek między udziałem procentowym kenofitów a udziałem powierzchniowym obszarów zabudowanych i długością dróg oraz liczbą kenofitów i diafitów a intensywnością zaśmiecania. Uwagę zwraca niemal całkowity brak stanowisk gatunków synantropijnych, terofitów oraz antropofitów w granicach torfowisk wysokich i przejściowych.
- Mapa zróżnicowania wartości wskaźnika zawartości materii organicznej w podłożu wskazuje, że gleby bogate w materię organiczną koncentrują się współcześnie w granicach torfowisk wysokich, a także w dolinach rzek Piaśnicy, Białogórskiej Strugi i Czarnej Wdy. Fragmenty terenu najuboższe w humus są natomiast zlokalizowane w rejonie Łąk Dębkowskich, Karwieńskich Błot oraz u podnóża Kęp Ostrowskiej i Sławoszyńskiej. Na obrzeżach torfowisk, które miały w przeszłości charakter organiczno-mineralny, na skutek osuszenia terenu i użytkowania rolniczego, doszło do decesji cienkiej warstwy humusu. Zubożenie gleby w materię organiczną w centrum badanego terenu, np. w rejonie wsi Karwieńskie Błota, jest wynikiem długotrwałej, intensywnej antropopresji (teren najdłużej użytkowany przez człowieka, poddany melioracjom odwadniającym już w XVI wieku).

Wnioski

- Antropogeniczne przemiany, jakie nastąpiły na torfowiskach przymorskich w wiekach XIX i XX, doprowadziły do zaniku siedlisk ahemerobnych oraz do redukcji przestrzennej i fragmentacji siedlisk oligohemerobnych, przy jednoczesnym wzroście areału siedlisk o wyższych stopniach hemerobii. W efekcie tego procesu doszło do powstania mozaiki siedlisk wtórnych i wybitnego zwiększenia różnorodności florystycznej terenu.
- Obecny stopień synantropizacji flory jest związany nie tylko z formą i natężeniem antropopresji, lecz również z pierwotnym ekologicznym zróżnicowaniem torfowisk, przy czym siedliska torfowisk wysokich i przejściowych cechują się większą odpornością na ekspansję gatunków obcych siedliskowo i geograficznie niż siedliska torfowisk niskich.
- Mimo daleko posuniętej transformacji, przebiegającej przede wszystkim w kierunku eurytopizacji i allochtonizacji, współczesna flora torfowisk przymorskich zachowała część swoistych cech, związanych z charakterem geologicznym i zróżnicowaniem typologicznym siedlisk, a także z położeniem geobotanicznym. Postęp synantropizacji flory na zaburzonych siedliskach torfowych i jego ewentualne skutki w postaci całkowitego zastąpienia flory naturalnej przez wtórną lub zatarcia różnic florystycznych między siedliskami wysokotorfowiskowymi a niskotorfowiskowymi wymaga dalszych badań.

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