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Vegetation and flora in the vicinity of salt and brine extraction sites in the western part of Kuyavia (Poland)

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Abstract. The paper presents a syntaxonomic and floristic analysis of salt marshes formed at the soda factories in Mątwy and Janikowo, the salt mine in Góra, and the salt works and spa hospitals in Inowrocław. In the study area delineated in this region, the analysis also covered salt marshes formed in places of failure of pipelines supplying brine to industrial, medical and recreational facilities, as well as those discharging saline industrial and municipal wastewater were also analysed.
A total of 611 relevés were taken using the Braun-Blanquet method in 215 inland salt marshes occurring in the study area during four consecutive growing seasons (1998-2001). A numerical classification of this set of relevés and of 124 taxa of vascular plants recorded in these relevés was carried out using TWINSPAN. Taxa from the prepared floristic list were assigned to five geographical and historical groups, and the percentage of species of these groups was determined for the saltmarsh flora of the study area.

It was found that most of the groups of relevés distinguished at successive levels of hierarchical divisive classification, performed based on differential species, correspond through their species composition to six (out of seven) syntaxa of halophytic vegetation distinguished in the studies conducted about 40 years ago in the entire area of Kuyavia. Of the total number of 124 taxa, 14 species of halophytes were identified, including six obligate and eight facultative ones. The number of taxa in the geographical and historical groups was as follows: 22 spontaneophytes, 73 apophytes, 16 archaeophytes and six kenophytes. No diaphytes were found in the study area, however, seven species of cultivated plants were recorded.

Keywords: flora, halophytes, inland saltmarshes, ecological hazard area, soil salinity, relevés, numerical syntaxonomy.

1. Introduction

The occurrence of halophytes in the western part of Kuyavia is mainly determined by anthropogenic factors related to the exploitation of salt and brine deposits. The ecological effects of this exploitation have been monitored by botanists since the mid-19th century, i.e. since the launch of a salt mine and soda factory in what was then Mątwy, now a district of the town of Inowrocław. The history of mining and salt and soda industry, as well as botanical and phytosociological research conducted in this region is presented by Karasińska et al. (2021) in a study published in *Ecological Questions*. The study compares the occurrence and population resources of 18 species of halophytes at 65 sites located in meadows at Lake Gopło (study area G) in the valuable natural area of the Gopło Landscape Park and 90 sites in meadows located on the Noteć Canal (i.e. study area N presented in this work), where two soda factories have been operating since the 1870s and the 1950s at settling ponds of saline lime sludge in the environmental risk area. The flora of halophytes on two plots subjected to different types of human impact differs significantly. In the area with natural soil salinity caused by groundwater, mainly facultative halophytes occur, while obligate halophytes occur sporadically (13 halophytes in total, including 11 facultative and two obligate species). On the other hand, in the area with strong saline water inflow generated by economic activity, the flora of halophytes is richer (16 species in total), especially in obligate species (six), and the population resources in both groups of species are very high.

In this new study, we present the distribution and structure of phytocoenoses with halophytes growing on saline soils in the aforementioned area N and the area adjacent to it from the east, which includes the salt mine in the village of Góra near Inowrocław and areas with pipelines transporting brine from the mine to the soda works. The study also focuses on the analysis of the flora occurring on saline soils within the surveyed phytocoenoses.

The objective of the study was to find answers to the following questions:

- what is the variability of the halophytic plant communities occurring in the area?
- what is the species richness and geographic–historical spectrum of the flora on the salt marshes of the area?
- how does the flora of the study area differ from the floras of other areas with halophytes in terms of the proportion of geographic–historical groups of species?

2. Study area

According to the current administrative division of Poland, the study area is located in the western part of the Kujawsko-Pomorskie Province, while according to Solon et al. (2018) physical and geographical regionalisation, the area belongs to the Greater Poland Lakeland macroregion (315.5) and includes two mesoregions: Inowrocław Plain (315.55) and Żnin-Mogilno Lakeland (315.58).

In geobotanical terms, the area is part of the Great Valleys Belt subdivision, the Greater Poland and Kuyavia region, and the Kuyavia district (Szafer & Zarzycki, 1972). In the study *“Krajobrazy roślinne i regiony geobotaniczne Polski”* (Vegetation landscapes and geobotanical regions of Poland), Matuszkiewicz J.M. (1993) includes the area in the so-called Black Kuyavia district within the Greater Poland and Kuyavia subregion.

The geological structure and hydrology of the study area and other natural factors determining the occurrence of halophytes are presented in the aforementioned study by Karasińska et al. (2021). The study also provides detailed information on anthropogenic conditions related to land use and the development of mining, salt and soda industry over the past 150 years, as well as information on the implementation of environmentally friendly technologies and treatments to prevent soil salinisation and to restore soils over the past 30 years.

The location of the study area (area N) in Poland and the location of relevés with halophytes in relation to the Noteć River, the Noteć Canal, the settling ponds at the two soda factories, as well as other technical infrastructure facilities is presented in Figure 1.

3. Methods

Data on the structure of phytocoenoses were obtained from the work by Karasińska (2004), who carried out her fieldwork during the 1998–2001 growing season. Based on the results of field research presented in the works of Karasińska (1990, 2000), Karasińska and Nienartowicz (1998), Piernik et al. (1996), and Piernik (2000, 2003), sites of saline soils with halophytic vegetation were identified.

Relevés were taken at these sites, delimiting a homogeneous area within which species were censused and their cover was quantified by using the method and scale of Braun-Blanquet (1951). If halophytic vegetation persisted in one to three consecutive growing seasons, relevés were repeated at these sites. A total of 611 relevés were taken at 215 sites. A list of species present in all relevés was compiled. The nomenclature of vascular plants was mainly adopted after World Flora Online (2023) and, in the case of earlier names of halophytes, also according to Mirek et al. (2020).

Species composition and cover-abundance of species in each relevé were recorded in raw tables. Hierarchical classification dividing these relevés and species was performed using the TWINSPAN programme (Hill, 1979; Hill & Šmilauer, 2005). When transferring the data to TWINSPAN, the Braun-Blanquet cover-abundance scale was transformed into the following ordinal scale: r – 1; + – 2, 1 – 3; 2 – 5; 3 – 7; 4 – 8, 5 – 9 (Janssen, 1975). Calculations were made up to level 6, using three cut levels: 1, 3 and 7, without assigning weights to pseudospecies, and using the number of potential indicators as 5 and the minimum abundance of objects in the final group as 2. Both dendrograms show the division of the dataset up to level 6, but only groups distinguished at level 4 of the division were included in the classification of relevés. Groups of relevés distinguished by the TWINSPAN program at various levels of dichotomous division were compared with syntaxonomic units of different ranks in the hierarchical system of the current classification of plant communities in Poland developed by Matuszkiewicz W. (2022) and with the units of the classification of halophytic communities in Kuyavia presented 60 years ago by Wilkoń-Michalska (1963).

In both divisions, particular attention was paid to the number of obligate and facultative halophytes in the groups of relevés and species distinguished by TWINSPAN. Halophytes were classified as obligatory or facultative on the basis of the studies by Wilkoń-Michalska (1963), Warot et al. (2001) and Twerd (2012).

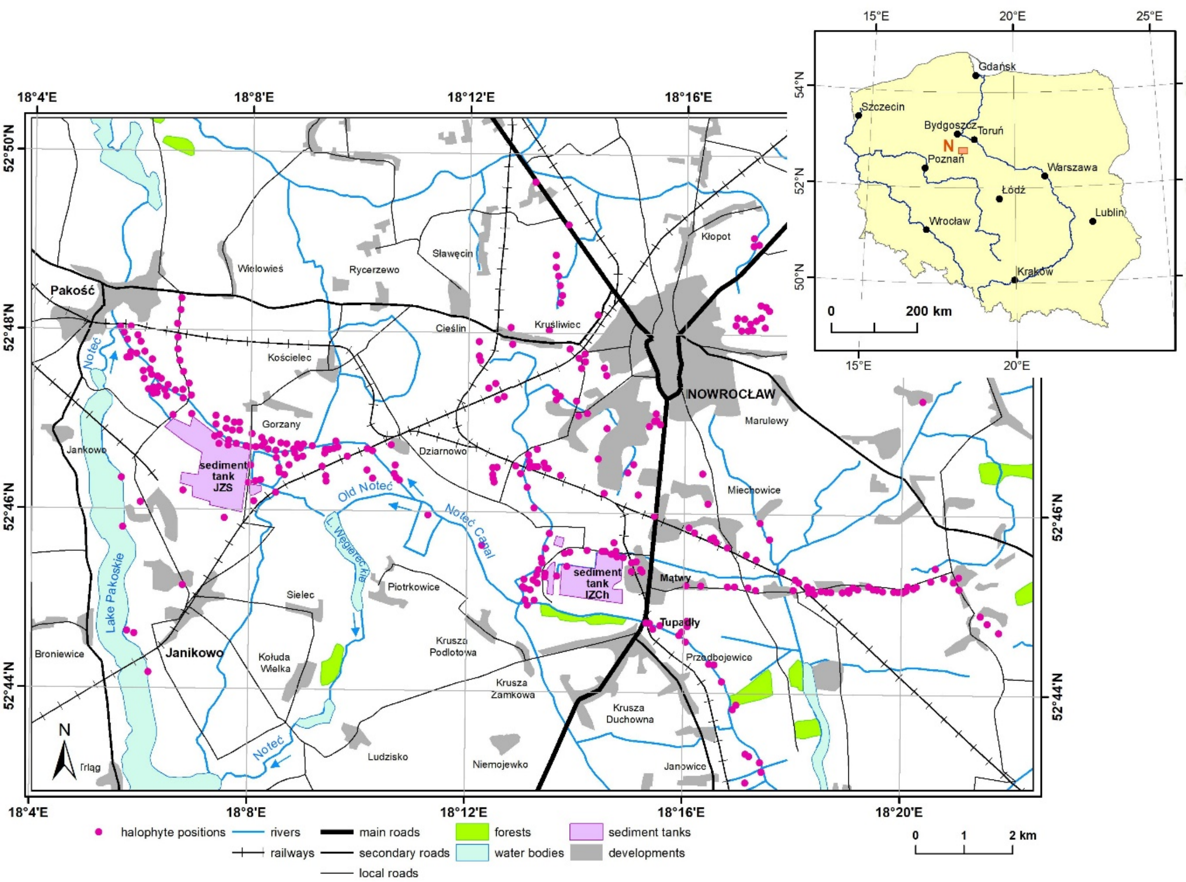

Figure 1. Distribution of the analysed vegetation patches with halophytes in relation to water bodies and technical infrastructure in the study area N

Geographical and historical classification, based on the origin and degree of domestication of species, was carried out as suggested by Kornaś (1968) and Mirek (1981). The following geographical and historical groups were distinguished in the set of species recorded in the flora of our study area:

- non-synanthropic spontaneophytes – native species found only on natural and semi-natural habitats,
- synanthropic spontaneophytes, or apophytes – native species, domesticated in anthropogenic habitats,
- archaeophytes – species that arrived or originated before 1492, i.e. permanent domesticates,
- neophytes (also known as kenophytes) – species that arrived or originated after 1492, i.e. permanent domesticates,
- diaphytes – plant species of foreign origin, which are temporarily present in the flora of Poland and have failed to become permanently domesticated. This group may include locally cultivated plants that 'escaped' from cultivation and are growing not on arable land, but spontaneously in other habitats. However, if such plant species were planted by humans in a specific place, i.e. not found there by chance, they are included in a separate group of cultivated plants. Such group of species was also distinguished in this study.

The affinity of species forming our flora with geographical and historical groups was mainly based on the floristic studies by Chmiel (1993) and Kamiński (2014).

The percentage of individual groups of species in our flora was compared with the spectra of geographical and historical groups of nine floras from other parts of Kuyavia and Greater Poland with saline soils or parts of these regions with a clear predominance of non-saline soils. The comparisons also included a spectrum of geographical and historical species groups of inland salt-marsh vegetation in Poland, prepared on the basis of the study by Piernik (2012). A dendrogram based on the distances between the spectra of the 11 floras was prepared using the Ward's method and the PAST software package (Hammer et al., 2001).

4. Results

4.1 Diversity of saltmarsh phytocoenoses

The hierarchical classification dividing the 611 relevés at level 1 of divisions distinguishes two subsets containing 266 and 345 relevés. They are located on the left and right branches of the dendrogram (Fig. 2). According to the TWINSPAN documentation by Hill (1979), relevés of these subsets are referred to as items of the negative group and items of the positive group, respectively. The analysis of their species composition presented in Table A1 from the Appendix shows that the left, negative branch of the dendrogram contains relevés from the initial communities growing in the area of unstable vegetation. Many of the 266 relevés were taken in the vicinity of fields, or even in agricultural crops, i.e. in areas disturbed by agrotechnical treatments. Relevés classified into the positive group come from grasslands, i.e. more stable ecological systems characterised by higher soil compaction and moisture content, as well as higher soil salinity.

In general, at level 1 of the division, large differences can be observed in the occurrence of halophytes in the left and right main branches of the dendrogram. The relevés of the left branch contain a total of nine species of halophytes, including four obligate and five facultative ones. *Salicornia europaea* and *Tripolium pannonicum* are not present in any of these relevés. Only the facultative halophytes *Puccinellia distans* and *Trifolium fragiferum* reach high frequencies. The right branch contain 16 species of halophytes, including six obligate and 10 facultative ones. All relevés with the obligatory species *Salicornia europaea* and *Tripolium pannonicum* are present here. In many of them, these species reach high cover.

At the level 2 of division, the group of 266 relevés was divided into two subsets – a negative one comprising 210 relevés characterised by high frequency of many species of weeds and ruderal plants (*Rorippa palustri*s, *Stellaria media*, *Senecio vulgaris*, *Chenopodium album*, *Ch. glaucum*, *Atriplex patula*, *Polygonum aviculare*), as well as obligate halophytes (*Spergularia marina*, *Atriplex prostrata*), and a positive one with 56 relevés, which is distinguished from the negative one by the presence of the halophyte *Trifolium fragiferum* and the high frequency and abundance of species representing more stable meadow systems (*Taraxacum officinale* and *Achillea millefolium* – the latter species classified by Khan (2003) as a tolerant plant species).

The group of 345 relevés at level 2 was divided into the subsets of 288 relevés (negative group) and 57 relevés (positive group). The features that distinguish the first group from the second one are the high frequency of obligate halophytes: *Salicornia herbacea*, *Spergularia marina*, *Atriplex prostrata*, *Tripolium pannonicum* and their high abundance (usually above cut level 3). Indicators of the positive group, on the other hand, are aquatic species such as *Bidens tripartita* and *Eleocharis palustris*, as well as the facultative halophyte *Bolboschoenus maritimus* (Table A1 in the Appendix). Piernik (2012) and Szymańska et al. (2013) report that, in the vicinity of the soda factory in Mątwy, areas occupied by species of the positive group are characterized by much lower soil salinity compared to areas inhabited by species of the negative group.

At level 3, the relevés were differentiated into groups corresponding to higher and lower syntaxonomic units (class, order, associations) in the hierarchical system of classification of

plant communities with halophytes in Poland developed by Matuszkiewicz W. (2022). With respect to this classification, the three groups distinguished at this level in the left branch of the dendrogram, containing 100, 110 and 40 relevés, can be defined as communities relating (in terms of species composition, salinity factor, saltwater inundation) to the *Puccinellio-Spergularietum salinae* association (Feekes 1936) R.Tx. at Volk 1937), with the first group showing the most initial character.
The four groups distinguished in the right, more halophilic, branch of the dendrogram were described as: the group of 168 relevés – communities related to the *Puccinellio-Spergularietum salinae* association with the participation of *Atriplex prostrata*; the group of 120 relevés – communities dominated by the obligate halophytes *Salicornia europaea* and *Tripolium pannonicum*; the group of 35 relevés – communities from the order *Glauco-Puccinellietalia*; the group of 22 relevés – halophilic rushes in shallow brackish water and unused meadows degraded by frequent saltwater flooding.

Groups *I–XVI* distinguished at level 4 based on species reaching the highest constancy and cut levels (Table 1 A in the Appendix) were defined as follows:

group *I* – communities with *Chenopodium glaucum*, *Rumex maritimum* and *Puccinellia distans*;
group *II* – initial communities with the halophytes *Puccinellia distans*, *Spergularia marina*, *Bolboschoenus maritimus* and *Atriplex prostrata*, as well as the glycophytes - *Atriplex patula*, *Chenopodium glaucum*, *Lepidium ruderale*, *Polygonum aviculare*, *Tripleurospermum inodorum*, and other weeds of cultivated fields;
group *III* – communities with *Puccinellia distans* and *Spergularia marina*, as well as *Elymus repens*, *Polygonum aviculare*, *Tripleurospermum inodorum* and other weeds, and a small proportion of cultivated crops;
group *IV* – field communities with *Elymus repens*, *Chenopodium album*, *Plantago major* and *Polygonum aviculare*, moderate abundance of halophytes (*Puccinellia distans*, *Spergularia marina*, *Bolboschoenus maritimus* and *Atriplex prostrata*) and a large number of cultivated plants *Triticum aestivum* or *Hordeum vulgare*;
group *V* – community with *Puccinellia distans*, *Elymus repens*, *Taraxacum officinale*, *Artemisia vulgaris* and *Tripleurospermum inodorum*;
group *VI* – community with *Cichorium intybus*;
group *VII* – communities with *Trifolium fragiferum*, *Elymus repens*, *Cirsium arvense*, *Plantago major* subsp. *intermedia*, *Taraxacum officinale* and *Puccinellia distans* and *Bolboschoenus maritimus*;

group *VIII* – communities with *Trifolium fragiferum*, *Juncus compressus* and *J. articulatus*;
group *IX* – communities with *Atriplex prostrata*, *Puccinellia distans*, *Spergularia marina*, *Elymus repens* and *Phragmites australis*;
group *X* – community with *Puccinellia ditans*, *Spergularia marina* and *Atriplex prostrata*;
group *XI* – communities dominated by *Salicornia europaea* and a smaller contribution of *Puccinellia ditans* and *Spergularia marina*;
group *XII* – communities with *Tripolium pannonicum*, *Puccinellia ditans* and *Salicornia europaea*;
group *XIII* – communities with a high frequency of *Plantago anserina* and *Plantago major* subsp. *intermedia* and a lower frequency of the halophytes *Puccinellia distans*, *Triglochin fragiferum*, *Triglochin maritimum* and *Lysimachia maritima*;
group *XIV* – communities of neglected, salt water flooded meadows with *Potentilla anserina*, *Trifolium repens*, *Cirsium arvense*, *Scorzonera autumnalis*, *Plantago major* subsp. *intermedia* and halophytes: *Puccinellia distans*, *Triglochin maritimum*, *Lysimachia maritima* and *Festuca arundinacea*;
group *XV* – communities related to *Scirpetum maritimi* (with *Bolboschoenus maritimus*, *Schoenoplectus tabernaemontani*, *Phragmites australis*);
group *XVI* – communities with *Tripolium pannonicum*, *Festuca arundinacea* and species of the *Phragmitetea* class (*Bolboschoenus maritimus* and *Phragmites australis*).

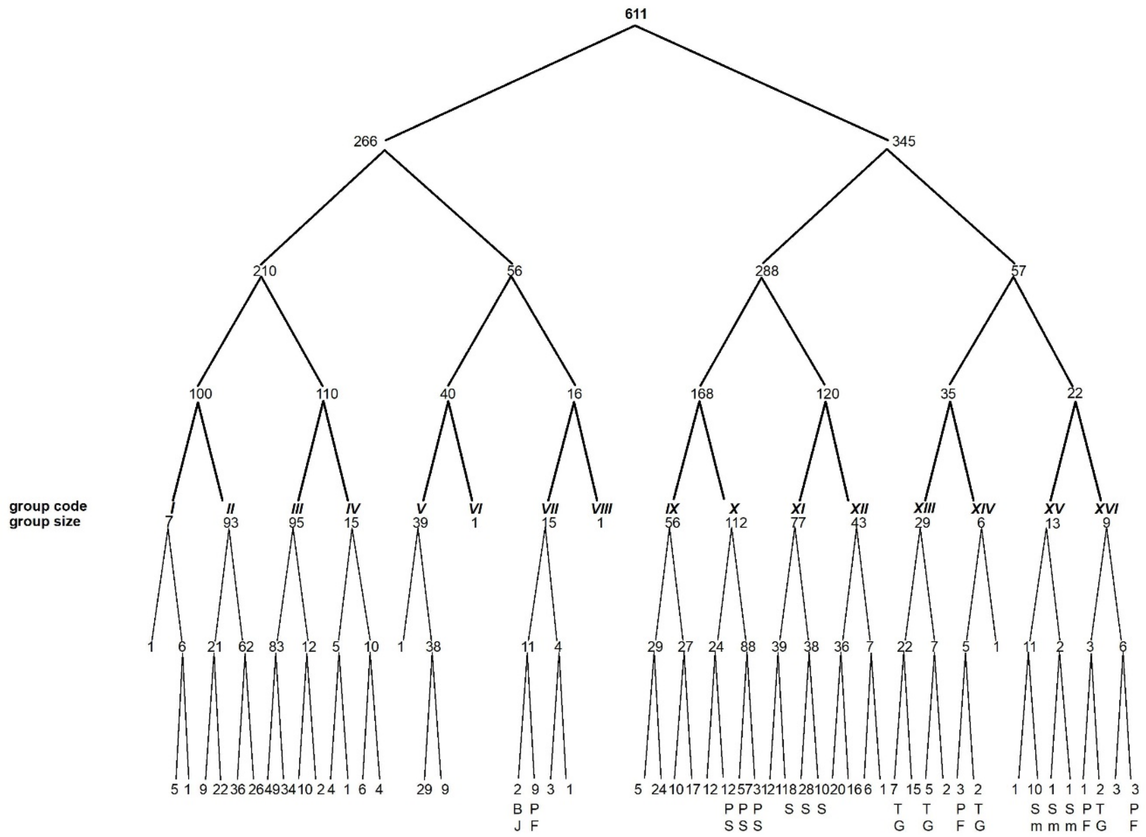

Figure 2. Divisive classification of 611 relevés by TWINSPAN. Roman numerals (*I*–*XVI*) denote codes of groups of relevés distinguished at the fourth level of division; Arabic numerals denote the number of relevés in the entire data set or in groups distinguished at subsequent levels of dichotomous division; the letter symbols under the dendrogram indicate groups at level 6 of the division containing relevés typical of the associations: *Blysmo-Juncetum compressi* – BJ, *Potentillo-Festucetum arundinaceae* – PF, *Puccinellio-Spergularietum salinae* – PS, *Puccinellio distantis-Salicornietum brachystachyae* – S, *Triglochino-Glaucetum maritimae* – TG, *Scirpetum maritimi* – Sm.

At the final level, i.e. level 6, used as the default level in TWINSPAN, some distinguished groups show a large proportion of relevés with the composition and combination of species typical of six plant associations, as shown at the bottom of the dendrogram in Figure 2. Relevés of *Blysmo-Juncetum compressi* Libb. 1930) R.Tx. 1950 and *Potentillo-Festucetum arundinaceae* R.Tx. 1933) Nordh. 1940 were separated after further divisions of group *VII*, *Puccinellio-Spergularietum salinae* (Feekes 1936) R.Tx. at Volk 1937 of group *X*, *Puccinellio distantis-Salicornietum brachystachyae* (Wilkoń-Michalska 1963) R.Tx. 1974 of group *XI*, *Triglochino-Glaucetum maritimae* Wilk.-Mich. 1963 of groups *XIII*, *XIV* and *XVI*. After divisions within the last group, relevés of the *Potentillo-Festucetum arundinaceae* association were also singled out.

4.2 Classification of species

The dichotomous divisive classification split the set of 124 taxa present in 611 relevés into two subsets of 59 and 65 taxa (Fig. 3). The former subset is dominated by ruderal and segetal species, accompanied by some cultivated plant species and species usually found in neglected, less intensively used meadows. Of the halophytes, only *Puccinellia distans* (a facultative species) was present in this subset. This species occurred with a rather high frequency in almost all distinguished groups of relevés (Table 1A in the Appendix) and for this reason it was not considered an indicator at the subsequent levels of dichotomous subdivisions of relevés. In the classification of taxa at level 2 of division, *Puccinellia distans* was included in the positive group comprising only seven taxa, and at level 4 it formed a single-element group – group *R* (Fig. 3).

Most of the halophytes (15 species) at the first level of division were included in the positive group of 65 taxa. At the next level, 14 of them were included in the negative group consisting of 53 items and only one facultative halophyte, *Trifolium fragiferum*, was included in the positive group consisting of 12 items (Fig. 3). At level 6 of division, 14 species of halophytes were included in eight groups. The largest number of them, i.e. seven species (including two obligate and five facultative halophytes) were included in group *o* consisting of 23 items. One species each of obligate halophytes was included in groups *f*, *i*, *j*, *k*, and one species each of facultative halophytes in groups *h*, *m*, and *n* (Fig. 3).

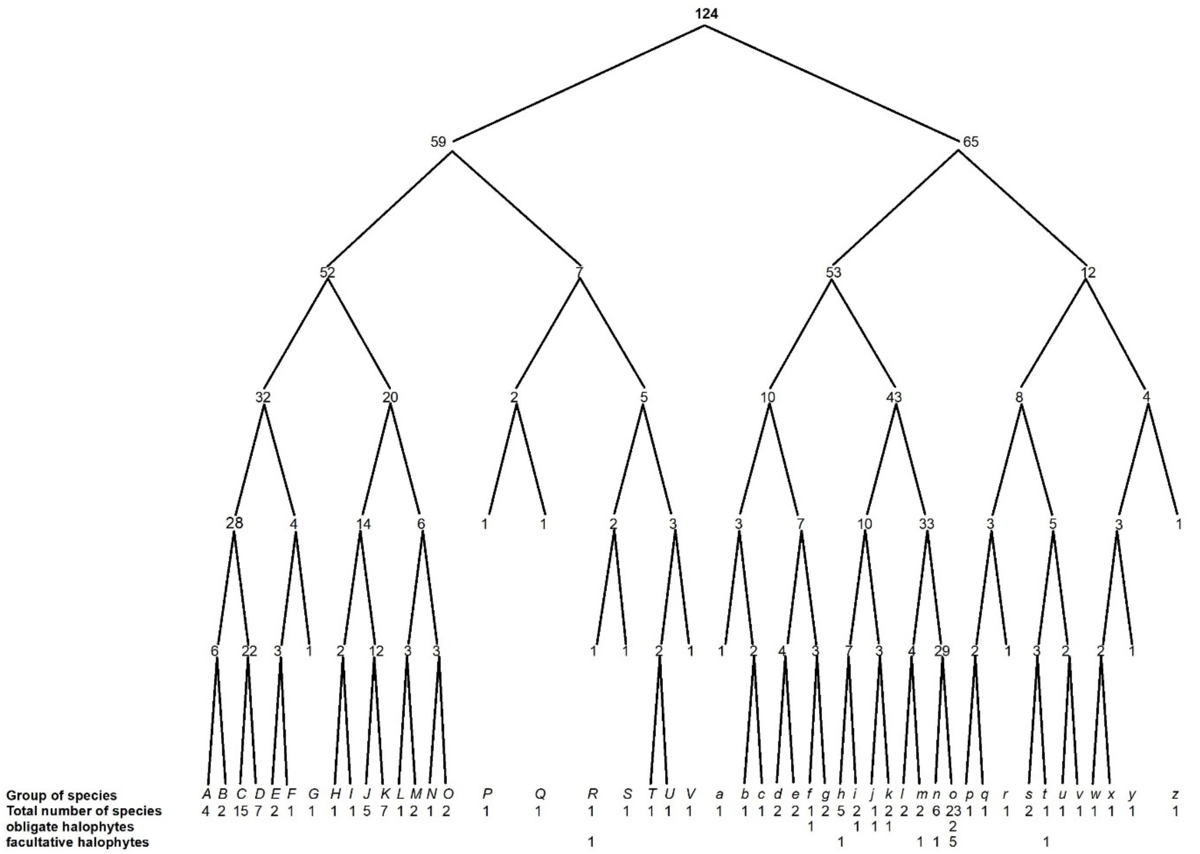

Figure 3. Divisive classification of 124 taxa present in 611 relevés carried out up to the sixth level of division

4.3. Spectrum of geographical and historical species groups

Of the total number of 124 taxa present in the analysed set of relevés. Spontaneophytes were represented by 22 species. Apophytes, represented by 73 species, were by far the dominant group. The abundance of archaeophytes and kenophytes, was 16 and six, respectively. The additional group of cultivated plants included seven species, i.e. 5.65% of the total number of species.

If cultivated plants were excluded, the percentage of categories in the flora of the study area, which includes 117 species, would be as follows: spontaneophytes 18.80%, apophytes 62.39%, archaeophytes 13.68%, kenophytes 5.13%, and diaphytes 0%. This spectrum of geographical and historical species groups compared to the spectra of biotopes with herbaceous, meadow, grassland and ruderal vegetation in the catchment of the Główna River, Greater Poland, and the flora of the Kujavia salt-marshes, is presented in Figure 4. These three spectra were included in Group B, which was distinguished in the middle part of the dendrogram obtained with the PAST software package (Fig. 5).

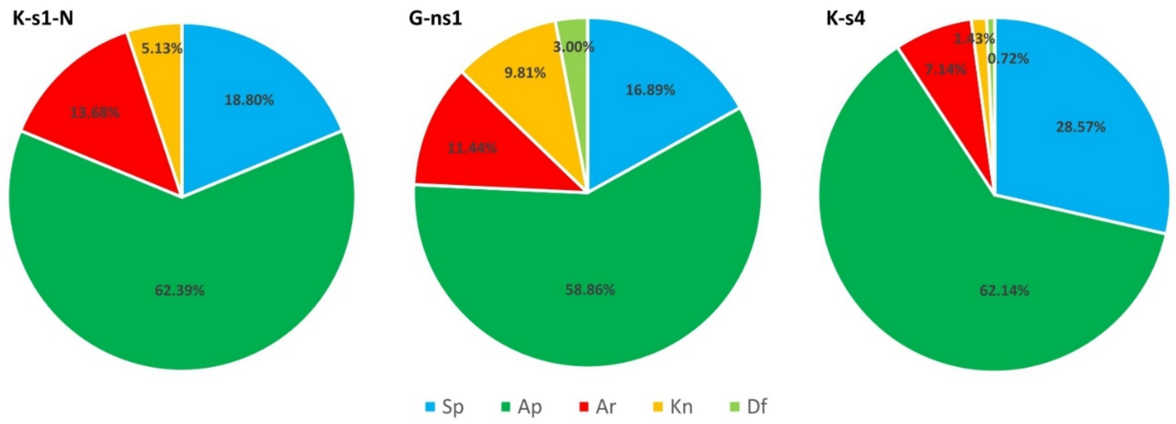

Figure 4. Percentage of geographical and historical groups of the three compared floras: K-s1-N – flora of the N study area, G-ns1 – flora of biotopes with herbaceous, meadow, grassland, and ruderal vegetation in the Główna River catchment in Greater Poland, K-s4 – flora of salt marshes of the entire Kuyavia region. Symbols of species groups: Sp – spontaneophytes, Ap – apophytes, Ar – archaeophytes, Kn – kenophytes, Df – diaphytes.

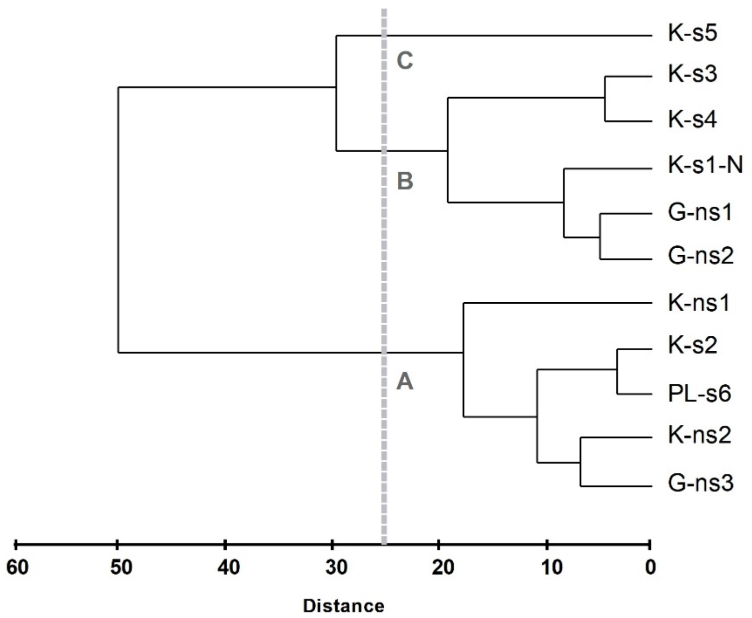

Figure 5. Comparison of geographical and historical spectra of species groups in the flora of the N study area and 10 other areas with vegetation on saline (s) and non-saline (ns) soils and substrates. Symbols of the compared sites: K-s1-N – Western Kuyavia, salt marsh vegetation on the banks of the Noteć River and the Noteć Canal, the study area N; K-s2 – East Kuyavia, Zgłowiączka River valley; K-s3 – Ciechocinek reserve of halophytes in 1954-1965; K-s4 – Kuyavia, halophytic plant communities of Kuyavia; K-s5 – Western Kuyavia, Mątwy and Janikowo towns, limestone heaps and salty lime sludge deposits; PL-s6 - Poland, inland salt marshes; K-ns1 – Southern Kuyavia, vegetation of hydrogenic soils, anthropogenic origin; K-ns2 – Kuyavia, Gniewkowo terain depression, shores of periodic floodplains in agricultural landscape; G-ns1 – Greater Poland, Główna River catchment, biotopes with herbaceous, meadow, grassland and ruderal vegetation; G-ns-2 - Greater Poland, Główna River catchment, mesophilous meadows and grasslands; G-ns3 - Greater Poland, Główna River catchment, flora of wet grasslands.

The distance between the K-s1-N spectrum from our study area and the G-ns1 spectrum from the Główna River catchment in Greater Poland was the smallest when comparing the studied flora to 10 others. This proves the high similarity of these floras despite their occurrence on soils with different salinity and the lack of diaphytes in the K-s1-N spectrum. The distance between K-s1-N and G-ns2, i.e. the spectrum of mesophilous meadows and grasslands in the catchment of the Główna River, was only slightly larger than between K-s1-N and G-ns1. The proportion of geographical and historical species groups of salt marshes in the entire Kuyavia region is most similar to the spectrum of the Ciechocinek reserve, which was also included in Group B.

The K-s5 spectrum of limestone heaps and saline lime sludge from the towns of Mątwy and Janikowo in Western Kuyavia is related to Group B over a large distance. This distinctiveness (i.e., the dissimilarity of this spectrum) is mainly due to the fact that spontaneophytes are not identified on the artificial substrate from which the heaps are formed. This spectrum, which is also characterized by a significant proportion of apophytes and archaeophytes, the largest of all 11 floras compared, can be considered a separate single-element group – Group C.

The spectra of other floras occurring on non-saline or saline soils of varying salinity and moisture content form a compact group – Group A – in the lower part of the dendrogram. These spectra show twice the proportion of spontaneophytes and a smaller proportion of apophytes compared to group B, which includes the spectrum of the flora we studied.

The percentage of the five geographical and historical species groups in the 11 floras compared and the sources of input data for calculating these values are presented in Table 2A in the Appendix.

5. Discussion

Of the 29 species of halophytes found in the Kuyavia region (database according to Warot et al., 2001; Twerd, 2012), 16 species were recorded in the salt marshes developed in the *N* area in the vicinity of brine extraction sites, salt and soda production infrastructure, spa and recreation sites, as well as saline sewage treatment facilities. These ranged from obligate halophytes, usually found in areas of high salinity, to facultative halophytes with a wide ecological range in relation to salinity, and semi-halophytes growing at sites with low salinity but high moisture content, often with stagnant water. In addition, a total of 108 glycophyte taxa with varying degrees of tolerance to substrate salinity were recorded in salt marshes. All 611 relevés contain 124 taxa at the sixth level of division, adopted in TWINSPAN as the default level, were divided into 55 groups. The analysis of the subdivisions at successive classification levels reveals that the main factor differentiating the relevés, which was marked at the first level, was the degree of sustainability of the community conditioned by the time of development.

It resulted in the division of the set into initial communities – field crops and ruderal communities, and permanent grassland communities. It was only at the subsequent levels that the salinity and moisture content played the role of a factor separating the two opposing subsets. The gradients of these two ecological factors played a major role in the ordination analysis of saltmarsh vegetation carried out for the entire region of Kuyavia by Nienartowicz and Wilkoń-Michalska (1993a, 1993b). Probably the high proportion of fields in the vicinity of the industrial plants causing disturbance and salinisation of the surrounding soils affected this result of the analysis.

Wilkoń-Michalska (1963), using the classical method of classification developed by Braun-Blanquet (1951), distinguished the following seven associations in the entire area of Kuyavia: 1 – *Salicornietum patulae* W. Christiansen 1955; 2 – *Puccinellia distans-Spergularia salina* Feekes 1936; 3 – *Triglochin maritimum-Glaux maritima* Wilk.-Mich. 1963; 4 – *Scirpetum maritimi* (W. Christiansen 1934) Tx 1937, the subassociation *Puccinellia distans* Boer 1942; 5 – *Festuca arundinacea-Potentilla anserina* (Tx 1937) Nordhagen 1940; 6 – *Blysmo-Juncetum compressi* (Libbert 1932) Tx 1950; 7 – *Arrhenatheretum elatioris* Tx 1937, the subassociation *lotetosum tenuifolii* Altehage 1940. The analysis of the species composition in the 16 groups of relevés, distinguished at level 4 of the TWINSPAN classification, shows that some of them clearly correspond to the first four syntaxonomic units mentioned. The relationship of the groups to the other three syntaxonomic units is less clear or almost absent.

Species characteristic of the *Festuca arundinacea–Potentilla anserina* association, occurring with rather low constancy in many of the species groups distinguished at level 4, did not meet the criterion of differential species in the initial divisions. Relevés with these species combinations, similar to those typical of this syntaxon, were only distinguished at level 6 after further divisions in groups *VII*, *XIV* and *XVI*.

Blysmus compressus, a species characteristic of the *Blysmo-Juncetum compressi* association, was recorded in only four vegetation patches out of a total of 611 relevés. Two relevés are included in group *VII* consisting of 15 relevés and two in group *IX* with a total of 56 relevés. *Juncus compressus* and *Trifolium fragiferum*, according to Wilkoń-Michalska (1963) characteristic species of the *Blysmo-Juncetum compressi* association, are also present in group *IX*. However, these three species do not occur in the same relevé.

Our analysis shows that no saltmarsh vegetation classified as *Arrhenatheretum elatioris lotetosum tenuifolii* occurs in the study area *N*, as *Arrhenatherum elatior* was not recorded in any of the 611 relevés.

Of the other six differential species of the association *Arrhenatheretum elatioris* Tx 1940 and the alliance *Arrhenatherion elatioris* Pawł. 1928 listed by Wilkoń-Michalska (1963), i.e. *Daucus carota*, *Bromus mollis*, *Hieracium sphondylium*, *Crepis biennis*, *Geranium pratens*e and *Rumex thyrsiflorus*, only the first one was present in the analysed set. In the classification of the relevés, *Daucus carota*, with low frequency and moderate abundance, was included in group *IV*, while in the classification of species – in group C/4 (Table 1A in the Appendix).

The comparative analysis of the spectra of geographical and historical species groups shows that the plant communities on the Noteć River and the Noteć Canal in the vicinity of soda factories, saltworks, salt mines and health resorts have retained the character of meadows and grasslands despite various human impacts. On the other hand, however, they have acquired the character of salt marsh vegetation. This is evidenced by the presence of Group B in the dendrogram, formed jointly by the spectrum of geographical and historical groups of species of the studied flora with spectra of grasslands on non-saline soils in the catchment of the Główna River in Greater Poland, and spectra of flora from the Ciechocinek halophyte reserve and the flora of salt marshes from the entire region of Kuyavia. The existence of salt marshes in Kuyavia, like those in our study area, is mainly maintained by the inundation of water with a high concentration of salt, either municipal water or waste water from industry, health care and recreation. The inflow of saline water into the soil, including brine concentrated at graduation towers in the salt production process and spilled onto the meadows from a large bathing pool, also determined the existence of abundant populations of obligate halophytes in the Ciechocinek reserve in 1954–1965.

The floras of Group B differed clearly in terms of the percentage of geographically historical species groups from the floras of Group A, which included spectra of halophilous vegetation from a fragment of the Zgłowączka valley in the eastern part of Kuyavia, the vegetation of inland salt marshes in Poland, and non-saline wet meadows and grasslands and vegetation around small freshwater reservoirs in Kuyavia and the Główna River catchment in Greater Poland. The spectra of group A were distinguished from the spectra of group B by a higher (on average twice) proportion of spontaneophytes, and a smaller proportion of archaeophytes and kenophytes, the latter two categories especially in the spectra of vegetation on very moist soils, often in places with stagnant water. The encroachment and persistence of spontaneophytes on the salt marshes in the Zgłowiączka valley and in various regions of Poland (in the vicinity of the towns of Pyzdry, Łęczyca, Busko, Wieliczka, and some in Kuyavia) may be facilitated by lower soil salinity, as revealed by analyses of the occurrence of species and indicator communities and measurements of soil salinity (e.g. made by Piernik, 2012). The persistence of these salt marshes is mainly sustained by processes of brackish water underseepage and not by abundant floods of water with high salt content. However, the reduction in the number of archaeophytes and kenophytes may be due to the fact that moist habitats are less susceptible to the encroachment of undomesticated plant species of alien origin (Ratyńska, 2003).

The high salinity of soils in the salt marshes of Kuyavia, especially those in the Ciechocinek halophyte reserve, which was flooded in the past, may also limit the penetration of new components into halophytic communities. On the other hand, species considered to be glycophytes adapt to the salinity of the substrate, becoming salt tolerant plant species. Both processes – reduction in the encroachment and adaptation to salinity – can lead to a similarity in the spectra of geographical and historical groups of non-saline meadow and salt marsh species.

6. Conclusions

The main conclusions resulting from the conducted analyses can be formulated as follows:

1. A total of 124 species of vascular plants were found in the salt marshes developed in the study area N as a result of the operations carried out by brine mining and salt production, spa facilities, and the disposal and treatment of saline waste and sewage.

2. Of the 124 species found, 16 species of halophytes occurred out of the 29 halophyte species recorded to date in the entire area of Kuyavia. This constitutes 55.2% of the halophytic flora of the region.

3. In the phytosociological, hierarchical and divisive classification of 611 relevés carried out with TWINSPAN, the main factor differentiating the set of relevés at the first level of division was the time of plant community development after anthropogenic disturbance. This factor resulted in the division of the relevés into two subsets, i.e. initial and stabilised plant communities.

4. At the 6th default level of division, as many as 55 groups of relevés were distinguished, between which a clear *continuum* was marked. The continuum was mainly due to the abundant presence of some facultative halophytes in many groups, including in particular *Puccinellia*

distans and *Atriplex prostrata*, as well as the presence of many species of glycophytes that tolerate salinity and are characterised by a wide ecological amplitude in relation to this factor.

5. The species composition of most of the 16 groups of relevés distinguished at the fourth (more generalised) level of division corresponded to four out of the seven syntaxa distinguished in Kuyavia by Wilkoń-Michalska (1963), i.e. the associations: *Salicornietum patulae; Puccinellia distans–Spergularia salina*; *Triglochin maritimum–Glaux maritima*, and the *Scirpetum maritimi* subassociation with *Puccinellia distans*. The presence of two other associations, i.e. *Festuca arundinacea–Potentilla anserina* and *Blysmo–Juncetum compressi*, was less pronounced at the lower levels of division. None of the groups corresponded to the *Arrhenatheretum elatioris lotetosum tenuifolii* subassociation.

6. The spectrum of geographical and historical groups of species distinguished for the analyzed flora can be considered as a structure typical of non-saline areas, but subjected to strong human impact, with tall herbaceous, meadow, grassland, and ruderal vegetation. However, the similarity between the spectra of the studied flora and the flora of salt marshes in the whole Kuyavia region, described by Wilkoń-Michalska (1963), is also clear.

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