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Original Research

Spatial Analysis of Plant Species Distribution in Midfield Ponds in an Agriculturally Intense Area

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Abstract

In an agricultural landscape small midfield ponds fulfill biocenotic and physiocenotic functions. A variety of species settle in areas of midfield ponds. The aim of our studies was to determine whether the occurrence of aquatic and marsh species in the studied bodies of water is a random effect or a result of spatial autocorrelation. On the basis of conclusions from ESDA, the hypothesis of spatial randomness can be rejected, which opens the way for searching spatial regimes. The review analysis of the spatial data (ESDA) with the use of join-count statistics showed that there is a positive spatial correlation for the midfield ponds in the agricultural area of the Pyrzyce-Stargard Plain in the distribution of ten aquatic and rush species for a distance of 1,250 m. The results of statistical analysis (ESDA) can constitute the basis for the choice and protection of midfield ponds as stop islands fulfilling functions of "mini" ecological corridors in spreading plant species.

Keywords: ponds, plant species, distribution, spatial autocorrelation, lattice model

Introduction

Western Pomerania includes numerous midfield ponds. The species composition of plants settling the midfield ponds also depends on: the stability of water table, bathymetrical factors of the water body (depth, surface of water table, etc.), the influence of land development, or their mutual vicinity [1-7].

Small midfield ponds play a significant role in the monotonous agricultural landscape by fulfilling important biocenotic and physiocenotic functions. In agricultural areas characterized by intensive farming, considerable conversion of the landscape takes place [8, 9]. The degree of the conversion of midfield ponds is shown by many factors, including anthropogenic changes of flora, and the midfield ponds of small surface and depth undergo the processes of overgrowing and terrestrialization most quickly [10, 11]. Physical phenomena modified by climatic changes accelerate these processes.

For the sake of important ecological functions of the bodies of water, it is crucial to use various methods of their protection related to the decrease in the trophy of these water bodies [12, 13]. Such an action helps to retain floristic diversity in the area of environmental islands, including midfield ponds [7, 14].

It was assumed that the midfield ponds found in the close neighborhood should be characterized by a similar species composition of plants, related to a similar relief, its development and accessibility to the water body resources. The aim of our studies was to determine whether the occur-

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rence of aquatic and marsh species in the studied bodies of water is a random effect or a result of spatial autocorrelation.

Materials and Methods

In the years 2003-05 floristic studies of 30 midfield ponds (average depth 0.9 m) were carried out on farming land of the Pyrzyce-Stargard Plain. The area of the studies is characterized by a large contribution of agricultural acreage (black-earth dominates in the Pyrzyce Plain) to a total surface of the land. In this area in the majority of water bodies the acceleration of the eutrophication process is observed, and this leads to the degradation of midfield ponds [15, 16]. In the area selected for studies, the average concentration of midfield ponds amounted to 22 objects/km^2, whereas in the neighboring areas – 2 midfield ponds/km^2 (Fig. 1). On the water table and in the littoral zone 33 plant species were determined, the names of which were given according to Mirek et al. [17].

Spatial autocorrelation is frequently encountered in ecological data, and many ecological theories and models implicitly assume an underlying spatial pattern in the distribution of organisms and their environment. In the landscape there are various floristic and faunistic habitats of different degrees of autocorrelation. An autocorrelation series is a series in which observations tend to correlate with neighboring observations in time or space. A positive spatial autocorrelation can result from the occurrence of microhabitats or from the spread of species. In the case of spatial autocorrelation the composition of plants settling neighboring midfield ponds are only slightly different from those settling in more remote places [18].

The analysis of spatial distribution of the midfield ponds was carried out using the CrimeSat software [19]. The program can analyze the distribution of the objects, identify hot spots, indicate a spatial autocorrelation, and monitor the interaction of events in space and time.

The analysis of the nearest neighborhood [20] was used to estimate the regularity of distribution. The statistical analysis of distribution of selected plant species among the midfield water bodies surveyed was based on a set of binary data on the presence or absence of each species in each pond. Statistics based on binary random variables (where present = 1, absent = 0) can then be calculated to determine whether the patterns of B's and W's are random or show some sort of clustering. Cliff and Ord [21, 22] developed three join-count statistics. For species presence/absence data, species status xi is either 1 (corresponding to B = 1) or (W = 0). BB join-counts represent the statistic for all pairs of sampling sites where both sites have a value of B (species present), BW join-counts represent the statistic for all pair of sites where one site is B (species present) and the other is W (species absent). The final join-count, WW, represents the statistic for all pairs of sites where both sites are W (species absent). The statistic BB and WW refer to a positive spatial autocorrelation, BW representing a negative autocorrelation.

The distribution of indicator plant species among midfield water bodies (30) was based on the identical assumption that the value of inter-site connection weights implies knowledge of dispersal rate between sites. The choice of weights (e.g. Euclidean distance) represents assumptions about habitats.

The analysis of spatial autocorrelation was performed with the R CRAN version 2.6.0 software [23], using join-

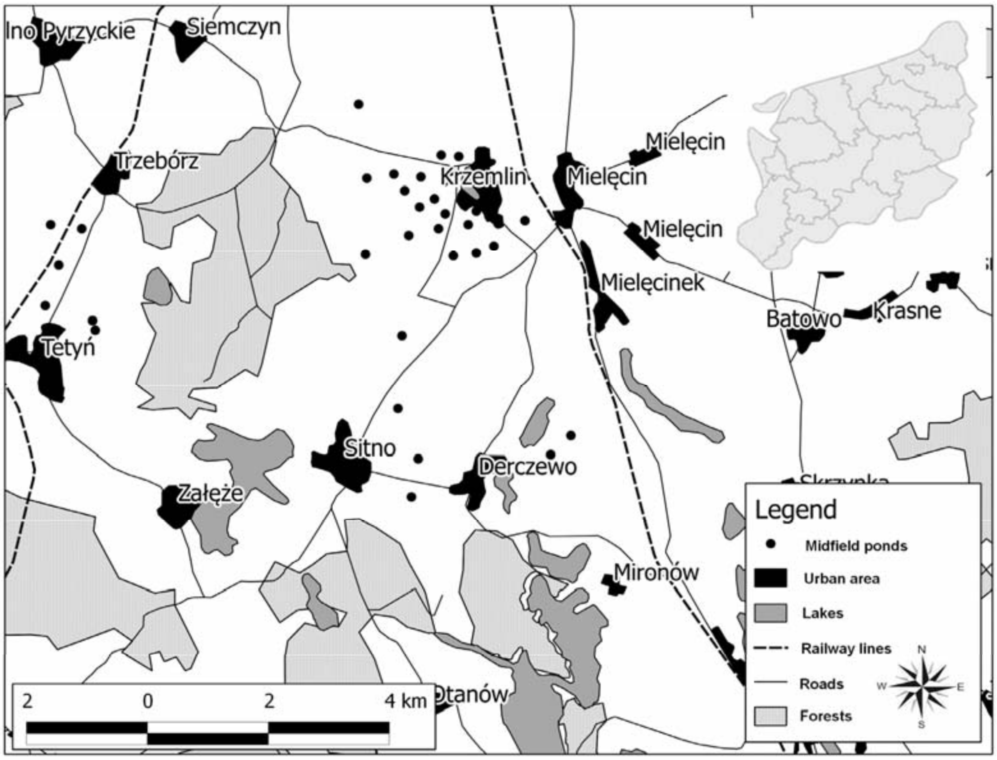

Fig. 1. Locations of midfield ponds.

count, the test routine of which is based on the non-free sampling approach assumptions. The null hypothesis tested assumed a random distribution of the species over the number of ponds where the species was present. The hypothesis was accepted when p-value >0.05. The alternative hypothesis (H1) assumed the presence of spatial autocorrelation, the correlation coefficient being >0; the alternative hypothesis was accepted when p-value <0.05 [24].

Results and Discussion

In the agricultural landscape the spread of plants can be strongly limited due to the fragmentation of this area. The area that they occupy depends on many factors. One of them is the appropriate distance between the islands and also the preference of these plant species as to the ways of propagation (anemochory, ornitochory, antropochory). The expansion of plants on the water table in the littoral zone depends on the trophy of the body of water and is responsible for its further changes, and this is used for evaluating the ecological state of bodies of water [25].

In the studied area climatic factors (low precipitation, strong insolation) and anthropogenic (land reclaiming) have a decisive effect on the level of water table in the analyzed midfield ponds. Differentiated time and spatial distribution of precipitation significantly affects the type and degree of the expansion of the species found in the littoral zone, e.g. *Glyceria maxima*, *Scirpus lacustris*.

The dynamics of species population depends on such factors as appropriate habitat conditions and biological possibilities of plant spread. Degradation and liquidation of habitats result in creating a situation in which a given area cannot fulfill physiocenotic functions and hence possibilities of spread are getting limited [6].

Statistical methods are indispensible in evaluation of randomness or autocorrelation in spreading plant species. The results of these analyses will make it possible to assess which of the studied midfield ponds fulfill a decisive physiocenotic function and thus ensure large species differentiation of these water ecosystems [3].

Ecological studies, due to a specific character of the anthropized habitat, allow for a smaller number of samples (<50) [26].

The analyses of species distribution among the midfield water table and littoral zone involved only those species indicative of hydrogenic habitats including water, marshland, mud, shrubs, and nitrophilous belonging to the seven classes: *Alnetea glutinosae*, *Artemisietea vulgaris*, *Bidentetea tripartiti*, *Lemnetea minoris*, *Molinio-Arrhenatheretea*, *Phragmitetea*, and *Potametea*. Species presence/absence (Table 1) was used to calculate join-count statistics. Five species are not included, because they appeared in one pond each and could not be considered as displaying a pattern amenable to statistical analysis: *Alisma plantago-aguatica*, *Alopecurus geniculatus*, *Lemna trisulca*, *Polygonum amphibium*, and *Ranunculus sceleratus*.

Explorative spatial data analysis (ESDA) involving join-count statistics showed the presence of spatial autocorrelation in the distribution of ten species among the mid-field water table and littoral zone ponds sampled. Autocorrelation was being sought using 10 radii of length ranging from 250 to 2,500 m. all the mid-field ponds in the area of study became connected with their neighbors when the radius reached 1,500 m. Table 2 summarized p-values of BB statistics for all the 34 species analyzed and for five autocorrelation search radii (1,000 to 2,500 m). For all the seven search radii, a spatial autocorrelation was detected in the distribution of four species: *Eleocharis palustris*, *Glyceria fluitans*, *Lemna minor*, and *Salix cinerea*. Most species showed a positive autocorrelation in their respective distributions at the search radius of 1,250 m; these were: from water species *Lemna minor* and *Elodea canadensis*; marshlands species *Carex acutiformis*, *Eleocharis palustris*, *Galium palustre*, *Glyceria fluitans*, *Iris pseudacorus*, *Lythrum salicaria*, and *Phalaris arundinacea;* and shrubby species *Salix cinerea*.

Fig. 2 showed all the possible connections between the midfield water table and littoral zone of ponds at the search radius of 1,250 m (was 102): 23 ponds show the lowest number of connections (about 5) with their nearest neighbours, while seven ponds had the largest number (8) of connections between all the ponds, at the search radius of 1,250 m.

The absence of a positive autocorrelation in distribution among the midfield ponds analyzed was shown both by the species distributed among a low number of ponds (e.g. *Alisma plantago-aquatica*, *Alnus glutinosa*, *Alopecurus geniculatus*, *Lemna trisulca*, *Lysimachia vulgaris*, *Polygonum amphibium*, *Ranunculus sceleratus*) and by some species present in many, or most, ponds (e.g. *Elodea canadensis*, *Glyceria fluitans*, *Lemna minor*, *L. gibba*, *Oenanthe aquatica*, *Phalaris arundinacea*, and *Rorippa palustris*). It may be assumed that the latter were the most successful in their dispersal among the available hydrogenic habitats in the area of study. Most species showing a positive spatial autocorrelation in their distributions were

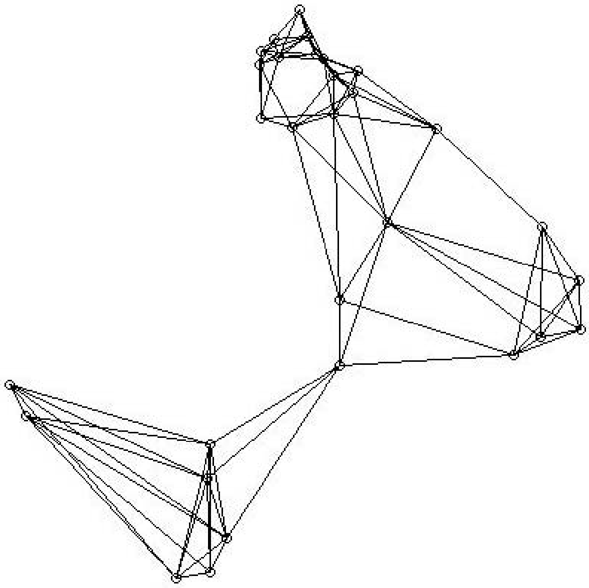

Fig. 2. A schematic diagram of the nearest neighbor selection of individual midfield ponds within a radius of 1,250 m.

Table 1. Indicator species presence/absence by water bodies.

Name of species	No. of ponds																													
Water species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Lemna minor	1	1	0	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	0	0	0	0	0	1	0	1	0
Lemna gibba	0	0	0	1	0	1	1	0	0	0	0	0	1	1	1	0	0	0	0	1	1	1	1	1	0	0	0	1	0	0
Myriophyllum verticillatum	0	0	1	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1
Elodea canadensis	0	0	0	0	0	0	1	1	0	1	0	0	0	0	1	1	0	1	0	1	0	1	1	0	0	0	1	0	0	0
Ranunculus circinatus	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Potamogeton crispus	0	0	0	1	0	0	0	1	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lemna trisulca	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polygonum amphibium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Marshlands species																														
Carex acutiformis	0	0	0	0	0	1	1	0	0	0	0	1	1	1	1	0	0	0	1	0	1	1	0	0	1	0	0	1	0	0
Carex rostrata	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	0
Phalaris arundinacea	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	1	1	1	1	0	1	1	1	0	0	0	0
Iris pseudacorus	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	0	0	0	0	1	0	0	0	0	0
Glyceria maxima	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Glyceria fluitans	1	1	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0
Oenanthe aquatica	1	1	1	1	1	1	0	0	0	1	0	1	0	1	1	1	0	1	0	0	0	1	0	1	1	1	0	1	1	0
Rorippa amphibia	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0
Phragmites australis	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	0
Scirpus lacustris	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0
Eleocharis palustris	0	0	0	0	0	0	1	1	0	0	0	1	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Agrostis stolonifera	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Lysimachia vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0
Lythrum salicaria	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Galium palustre	0	0	0	0	0	0	0	0	1	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Alisma plantago-aquatica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Muddy species																														
Rorippa palustris	0	0	1	0	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	0
Rumex maritimus	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0
Bidens tripartitus	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
Alopecurus geniculatus	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Ranunculus sceleratus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Shrubby species																														
Salix cinerea	0	0	0	0	0	0	0	1	0	1	1	1	0	1	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0
Solanum dulcamara	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0
Alnus glutinosa	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0
Nitrophilous species																														
Urtica dioica	1	0	1	0	1	0	0	1	0	1	1	0	1	0	1	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0

Explanations: 1 – presence; 0 – absence

Table 2. Summary of join-count analysis result.

Species	n	r [m]						
		1000	1250	1500	1750	2000	2250	2500
Lemna gibba	12	0.9437	0.8845	0.7914	0.7763	0.3401	0.3223	0.5901
Lemna minor	18	**0.0054**	**0.0063**	**0.0019**	**0.0007**	**0.0002**	**0.0022**	**0.0004**
Lemna trisulca	4	0.2489	0.3079	0.5479	0.5803	0.7320	0.8611	0.8620
Myriophyllum veriticillatum	8	0.5525	0.7455	0.889	0.8278	0.7783	0.3495	0.5676
Elodea canadensis	10	0.05503	0.05124	0.08983	0.03864	0.06347	0.2305	0.1154
Ranunculus circinatus	6	0.3252	0.4966	0.5608	0.6801	0.8600	0.7992	0.1951
Polygonum amphibium	4	0.7994	0.8861	0.4041	0.3714	0.5305	0.6887	0.3517
Potamogeton crispus	6	0.1769	0.1866	0.2174	0.2948	0.4210	0.3960	0.1161
Alisma plantago-aquatica	3	0.6090	0.6723	0.7260	0.7925	0.8472	0.9328	0.1890
Carex acutiformis	10	0.2545	0.0540	0.1585	0.1713	0.2912	0.2435	0.6233
Carex rostrata	5	0.3689	0.3859	0.4520	0.5879	0.7406	0.8877	0.5960
Phalaris arundinaea	10	0.1350	0.0582	0.2555	0.3832	0.5724	0.9236	0.9443
Iris pseudacorus	8	0.0934	0.05041	0.1480	0.2530	0.5050	0.5902	0.7239
Glyceria maxima	5	0.3894	0.4069	0.4411	0.2023	0.2568	0.2144	0.2213
Glyceria fluitans	14	**0.01355**	**0.01491**	**0.0028**	**0.0010**	**0.0018**	**0.0278**	**0.0131**
Oenanthe aquatica	18	0.6216	0.4130	0.4762	0.7013	0.8687	0.6597	0.8966
Rorippa amphibia	9	0.5833	0.5659	0.6846	0.6428	0.4446	0.5368	0.7523
Phragmites australis	7	0.2194	0.3163	0.4548	0.5814	0.8132	0.9229	0.8491
Scirpus lacustris	5	0.7148	0.8326	0.5035	0.5578	0.3466	0.5846	0.8648
Eleocharis palustris	7	**0.0037**	**0.0005**	**0.0005**	**0.0028**	**0.0081**	**0.0360**	**0.0431**
Lysimachia vulgaris	3	0.0658	0.1685	0.2909	0.3513	0.3894	0.3903	0.4641
Agrostis stolonifera	7	0.3100	0.2030	0.1714	0.2764	0.2479	0.5174	0.8505
Lythrum salicaria	5	0.3312	0.02942	0.02387	0.03478	0.03889	0.1128	0.2135
Galium palustre	5	0.04745	0.02107	0.01635	0.02737	0.0481	0.0884	0.1433
Rorippa palustris	11	0.5957	0.7457	0.7727	0.8268	0.8875	0.6314	0.4569
Alopecurus geniculatus	4	0.8889	0.4399	0.7017	0.7223	0.8706	0.8432	0.9868
Bidens tripartitus	6	0.2450	0.5006	0.8084	0.9004	0.6360	0.4865	0.2009
Ranunculus sceleratus	2	0.6786	0.7478	0.7941	0.8220	0.8746	0.9314	0.1800
Rumex maritimus	7	0.5858	0.8072	0.8438	0.7815	0.8902	0.9625	0.9748
Salix cinerea	9	**0.01481**	**0.0086**	**0.0026**	**0.0009**	**0.0006**	**0.0099**	**0.0581**
Alnus glutinosa	3	0.6005	0.3616	0.2016	0.2021	0.2676	0.3545	0.4089
Solanum dulcamara	5	0.3009	0.3671	0.5862	0.6426	0.8163	0.9379	0.9978
Urtica dioica	10	0.6811	0.3524	0.2812	0.5405	0.3150	0.3548	0.5899

p – values for BB statistics, n – number of ponds in which a species was present, r – radius of spatial autocorrelations search, asterisks denot p-values considered significant (< 0.05) for this study.

present in 5-18 midfield ponds located at a search radius of 1,250 m (Table 2).

The midfield ponds described by Bosiacka et al. [26], also found in the agricultural catchment area, differ from the studied ponds in a larger depth and smaller moisture differentiation of littoral zone. The measured physical differences of the midfield ponds and the differences of their floristic composition can result from different hydrological and soil conditions of both areas. In the area of Weltyn Plain characterized by a lower degree of intensification of agriculture (lower soil quality class), a larger distance for the positive spatial correlation and the occurrence of slightly different species of aquatic plants (*Hottonia palustris* and *Spirodela polyrhiza*) were observed. In our own studies species related to the area of large moisture differentiation (*Alopecurus geniculatus*, *Rorippa amphibia*) prevail.

In the 30 midfield ponds studied, all the species found proved the moderate and high trophy of these water bodies. Some of these species (*Carex acutiformis*, *Lemna minor*, *Elodea canadensis*, *Iris pseudacorus*) are used in hydrophyte systems of municipal and industrial sewage treatment [27, 28]. For 10 species for which a positive spatial correlation was established (up to 1,250 m), their ecological scale ranges from mesothropic to eutrophic bodies of water and this, due to the depth of water bodies changing with time and connected with changeable concentrations of biogenic compounds, allows them to increase the occupied surface within the occupied water body as well as outside it. Such species as *Carex acutiformis*, *Phalaris arundinacea*, and *Salix cinerea* constitute a biogeochemical barrier for biogenic substances flowing down from arable fields to a body of water [29]. The large biomass of these plants can markedly influence the accumulation of compounds of nitrogen and phosphorus and this will result in a decrease in the concentration of these chemical elements in water during the vegetation period. The decrease in the trophy of water is conducive to the development of species characteristic of mesotrophic water bodies (*Galium palustre*, *Elodea canadensis*), but after the biomass decay, most of the nutrients are returned back to the water.

Conclusions

1. On the basis of the conclusions from ESDA, the hypothesis of spatial randomness can be rejected, which opens the way for searching spatial regimes.
2. The review analysis of the spatial data (ESDA) with the use of join-count statistics showed that there is a positive spatial correlation for the midfield ponds in the agricultural area of the Pyrzyce-Stargard Plain in the distribution of ten aquatic and rush species for a distance of 1250 m.
3. The results of statistical analysis (ESDA) can constitute the basis for the choice and protection of midfield ponds as stop islands fulfilling functions of "mini" ecological corridors in spreading plant species.

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