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A CLUSTER ANALYSIS OF ZOOPLANTKON NUMBERS IN THE VISTULA LAGOON

1. INTRODUCTION

Numerical taxonomy, and methods of cluster analysis in particular, have undergone very intensive development over the last fifteen years. Cluster analysis consists of distinguishing values of sub-sets corresponding to various random variables in a given single or multi-dimentional set of observations. Ruspini [12] was the first to introduce the original concept of "fuzzy sets", as given by Zadeh [13], into cluster analyses. Caliński's method [2], as described by Caliński and Harbasz [3], in the form of programmes attaining a cluster analysis through a matrix of distances between all the features, is also known. The method most frequently applied is Czekanowski's [6], consisting of putting sets into order and distinguishing of similar cluster sets. This method has played an important role in anthropology and has also been successfully applied in phytosociology and zoocenology [4, 5, 6, 7, 8].

Clustering tendencies of *Tendipedidae* larvae numbers in the lakes of southern Sweden, based on studies by Brundin, have been presented in the paper by Romaniszyn [9]. The principle of dualism proposed by this author, connecting the merits of the dendrite and of Czekanowski sets, was applied in studies on clusters of the zooplankton organisms of the southern part of the Baltic Sea [4], and on determining the similarity of stations in the Vistula Lagoon.

As regards the present studies, we wish to show how interdependent zooplankton species influence the order and division of clusters at stations in the Vistula Lagoon, and vice versa, how the various specific hydrological conditions at stations influence the species composition and numbers of zooplankton organisms.

The aim of the paper is an analysis of zooplankton clusters estblished on the basis of numbers, applying the definitions of similarity and distance [7, 8, 9].

2. MATERIAL

The material for the present study was collected during the following periods: March—November 1975; May—November 1977; February—November 1978. Zooplankton samples were taken from the same nine stations, at monthly intervals, during the years mentioned, distributed as follows: five (1, 2, 4, 6, 8) along the longitudinal cross-section of the Vistula Lagoon, and four (3, 5, 7, 9) along two lateral cross-sections (Fig. 1).

Detailed considerations concerning the physical and chemical factors of the water body studied are given in the papers by Różańska and Więcławski [10, 11], from which selected data is presented in Tables 6, 7, 8.

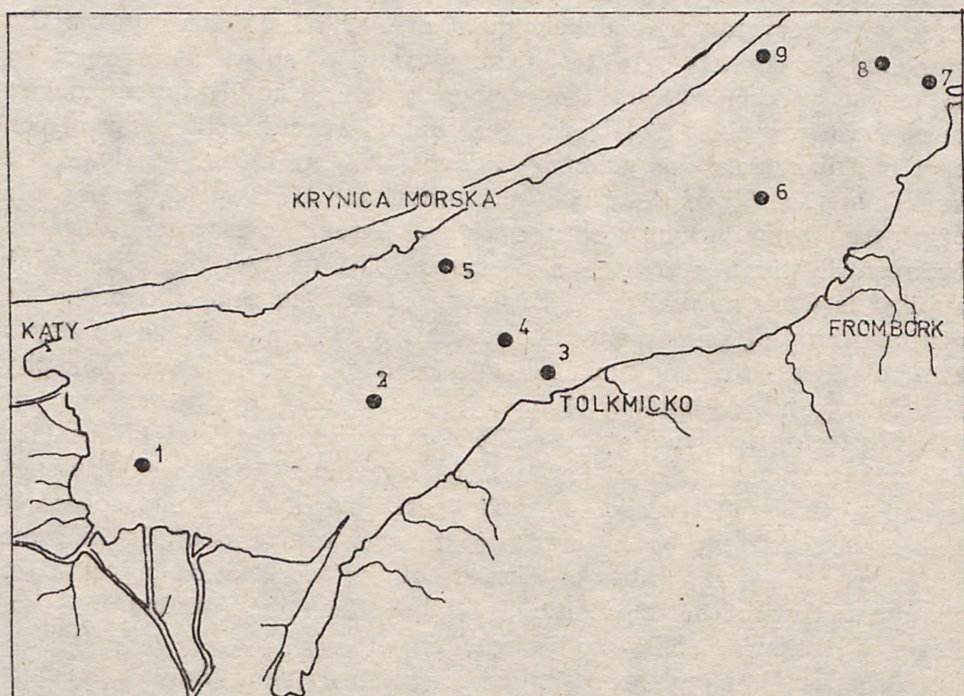


Fig. 1. Distribution of stations on the Vistula Lagoon during the period of investigations

Rys. 1. Rozmieszczenie stanowisk na Zalewie Wiślanym w okresie badań

3. METHODS OF INVESTIGATION

Samples were taken with a five-litre Ruttner sampler at 0, 1, 2, 3, and 4 m, depending upon the depth at the station. The samples were next filtered by means of a no. 25 Apsten-type net, then fixed with Utermöhl fluid and preserved in 4% formalin. During the laboratory work each plankton sample was brought to the volume of 50 ml for uniformity of countings. Microscopic examinations were carried out in a 1 cm^3 chamber. Altogether, 512 samples were collected and analysed microscopically (Table 1).

Table 1. Number of samples from the Vistula Lagoon stations during the period of investigation

Tab. 1. Liczba prób na stanowiskach Zalewu Wiślanego w okresie badań

Stations Stanowiska	Number of samples Liczba prób			Total number of samples Razem prób
	1975	1977	1978	
1	14	18	13	45
2	17	21	12	50
3	11	21	21	53
4	24	21	27	72
5	14	19	15	48
6	26	22	30	78
7	12	20	21	53
8	17	21	25	63
9	9	20	21	50
Total Razem prób	144	183	185	512

The number of individual taxonomic units subjected to an analysis of zooplankton clustering tendencies was expressed by the number of individuals in 1 m^3 of water (Tables 6, 7, 8).

The degree of similarity was expressed by the Marczewski and Steinhaus formula [8] as follows:

$$S=\frac{w}{a+b-w}100\%,$$

where: S — similarity of two compared sets of features,
w — number of common elements,
$a+b$ — sum value of elements of the sets or features compared.

The distance of the elements analyzed was defined in line with the above formula as:

$$r=\frac{a+b-2w}{a+b-w}100\%$$

The structure of dendrites and their linear system (Figs. 2, 3, 4, 5) was based on similarity analysis, abiding by the rule of the shortest distances. The method given by Florek [7] and Romaniszyn [9] was applied for the formation of the clusters.

Groupings for sets of stations were distinguished according to similarity of zooplankton and taxon numbers. All possible clusters of stations and taxons for the three year period of investigations were presented in the form of schemes (Tables 2, 3, 4, 5). Calculation of similarity coefficients were carried out on an "Odra-1204" computer.

4. RESULTS OF INVESTIGATIONS

The species composition and numbers of zooplankton organisms in the Vistula Lagoon showed certain differences for each particular year, therefore similarity analyses were carried out for each year individually.

Only taxonomic units falling within the systematic range genus — species were taken into consideration in clustering tendency analyses of zooplankton organisms, according to Romaniszyn's assuptions [9]. It was necessary to omit young *Copepoda* nauplial forms embracing an undefined number of species. Nauplial stages occurred in very large numbers at all of the stations [1].

The following taxonomic units were found in the material investigated:

Code number	*Rotatoria*
1	*Ascomorpha ecaudis* Perty
34	*Ascomorpha saltans* Bartach
2	*Asplanchna priodonta* Gosse
3	*Brachionus angularis* Gosse
4	*Brachionus calyciflorus* Pallas
5	*Brachionus calyciflorus amphiceros* Ehrenberg
6	*Brachionus dicersicornis* (Daday)
7	*Brachionus quadridentatus* Herman
8	*Brachionus urceolaris* Müller
9	*Brachionus rubens* Ehrenberg
33	*Cephalodella sp.*
10	*Euchlanis dilatata* Ehrenberg
11	*Filinia longiseta* (Ehrenberg)
16	*Kellicottia longispina* (Kellicott)
12	*Keratella cochlearis* (Gosse)
13	*Keratella cochlearis tects* (Gosse)
14	*Keratella criciformis* (Thompson)
15	*Keratella quadrata* (Müller)
17	*Lecane luna* (Müller)
18	*Notholca acuminata* (Ehrenberg)
19	*Notholca squamula* (Müller)
20	*Notholca striata* (Müller)

22	*Pedalia fennica* (Levander)
21	*Polyarthra dolichoptera* Idelson
23	*Polyarthra vulgaris* Carlin
24	*Proales sp.*
26	*Synchaeta sp.*
27	*Synchaeta litoralis* Rousselet
29	*Synchaeta monopus* Plate
36	*Synchaeta oblonga* Ehrenberg
28	*Synchaeta pectinata* Ehrenberg
38	*Synchaeta stylata* Wierzajski
31	*Trichocerca pusilla* (Lauterborn)
32	*Trichocerca sp.*
	C r u s t a c e a
41	*Bosmina coregoni maritima* (Müller)
42	*Bosmina longirostris* (Müller)
43	*Chydorus sphaericus* (Müller)
45	*Diaphanosmoma brachyurum* (Lievin)
46	*Evadne nordmanni* Loven
47	*Leptodora kindtii* (Focke)
48	*Pleuroxus uncinatus* Baird
49	*Podon plyphemoides* (Leuckart)
50	*Sida cristallina* (Müller)
51	*Simocephalus vetulus* (Müller)
74	*Acartia bifilosa* (Giesbrecht)
61	*Acartia longiremis* Lilljeborg
63	*Acartia tonsa* (Dana)
76	*Centropages hamatus* (Lilljeborg)
69	*Cyclops sp.*
65	*Eurytemora sp.*
67	*Mesocyclops leuckartii* (Claus)
77	*Pseudocalanus elongatus* Boeck
73	*Temora longicornis* (Müller)

4.1. GROUPS OF STATIONS RESULTING FROM SIMILARITIES OF THE NUMBER OF ZOOPLANKTON ORGANISMS

Clusters were obtained basing on the criterium of natural dendrite division, computing and comparing quotients of relevant distances. Similarity of numbers of zooplankton organisms (S) at stations in growing order, distances between stations (r) and quotients of adjacent distances are given in decreasing order for specific years as follows:

1975 min (max S) = 41.14%

S	r	d
41.14	58.86	
50.54	49.46	**1.190**

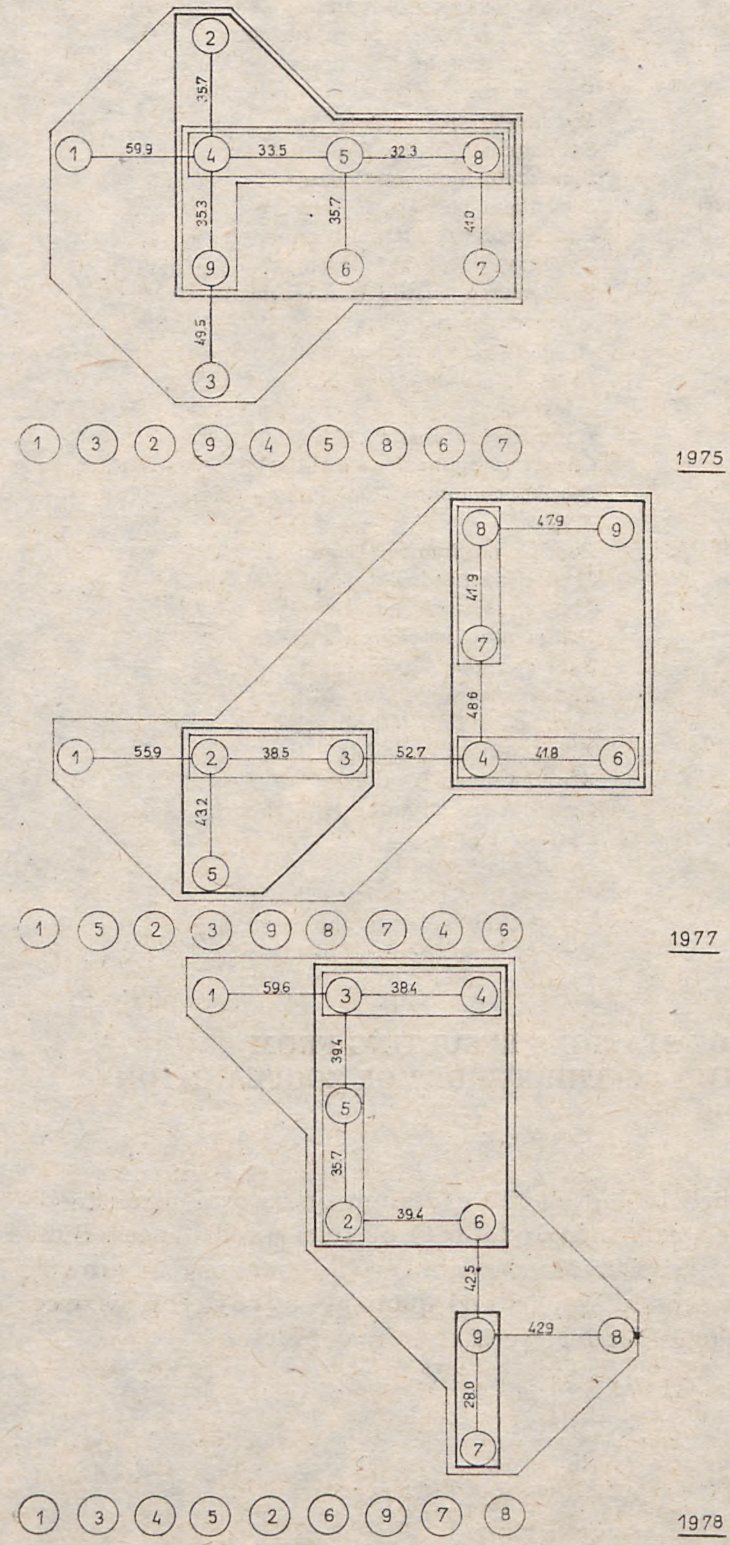


Fig. 2. Dendrites for 9 stations on the Vistula Lagoon in relation to zooplankton numbers during the period of investigations

Rys. 2. Dendryty 9 stanowisk Zalewu Wiślanego na tle liczebności zooplanktonu w okresie badań

50.04	40.96	1.207
64.31	35.69	1.148
64.35	35.65	**1.001**
64.71	35.29	**1.010**
66.54	33.46	1.054
67.69	32.31	1.035

The dendrite for stations breaks down into seven clusters at a similarity of $S = 67.69\%$, but a further two weaker divisions into three ($S = 59.04\%$) and six clusters ($S = 64.71\%$) are possible. Division of the dendrite into clusters is presented in Fig. 2, Table 2.

Table 2. Scheme of clusters for the Vistula Lagoon stations during the period of investigations

Tab. 2. Schemat skupisk stanowisk Zalewu Wiślanego w okresie badań

year / rok	similarity coefficient (%) / współczynnik podobieństwa	number of clusters / liczba skupisk	stations / stanowiska
			1 3 2 9 4 5 8 6 7
1975	59,04	3	(1) (3) (2 9 4 5 8 6 7)
	64,71	6	(1) (3) (2) (9 4 5 8) (6) (7)
	66,54	7	(1) (3) (2) (9) (4 5 8) (6) (7)
			1 5 2 3 9 8 7 4 6
1977	51,44	3	(1) (5 2 3) (9 8 7 4 6)
	56,82	5	(1) (5 2 3) (9) (8 7) (4 6)
	61,54	8	(1) (5) (2 3) (9) (8) (7) (4) (6)
			1 3 4 5 2 6 9 7 8
1978	60,56	4	(1) (3 4 5 2 6) (9 7) (8)
	61,62	6	(1) (3 4) (5 2) (6) (9 7) (8)
	72,00	8	(1) (3) (4) (5) (2) (6) (9 7) (8)

1977 min (max S) = 44.14%

S	r	d
44.14	55.86	
47.28	52.72	**1.059**
51.44	48.56	1.086
52.08	47.92	**1.013**
56.82	43.18	1.109
58.12	41.88	1.031
58.17	41.83	**1.001**
61.54	38.46	1.087

The dendrite for stations breaks down into eight clusters at a similarity of $S = 61.54\%$, but two divisions into three and five clusters are also possible. Division of the dendrite into clusters is presented in Fig. 2, Table 2.

1978 min (max S) = 40.37%

S	r	d
40.37	59.63	
57.14	42.86	1.392
57.53	42.47	**1.009**
60.56	39.44	1.076
60.57	39.43	**1.000**
61.62	38.38	**1.027**
64.29	35.71	**1.074**
72.00	28.00	1.275

The dendrite for stations breaks down into eight clusters at a similarity of 72.00%, but three divisions into 4, 6, and 7 clusters are also possible. Division of the dendrite into clusters is presented in Fig. 2, Table 2.

4.2. GROUPS OF SPECIES RESULTING FROM SIMILARITY OF NUMBERS

Taxon clusters were obtained from a natural division of the dendrite by comparing quotients of ordered distances min (max S) = 25.00% for all of the years. However, cenological distances (r) of taxons, quotients (d) of neighbouring sectors in diminishing order for particular years were as follows:

r	d	r	d	r	d
75.00		56.67	1.029	47,37	1.055
75.00	**1.000**	56.52	**1.003**	45.63	1.038
73.33	**1.023**	55.56	**1.017**	45.05	**1.013**
69.23	1.059	54.55	1.018	42.62	1.057
68.97	**1.004**	53.59	**1.017**	42.55	**1.002**
66.67	**1.034**	52.17	**1.027**	42.42	**1.003**
62.50	1.066	50.00	1.043	39.11	1.081
61.54	**1.015**	50.00	1.000	37.84	**1.036**
60.00	**1.026**	50.00	1.000	30.91	1.224
58.33	**1.029**	50.00	**1.000**	30.77	1.004

The dendrite for taxons breaks down into 29 clusters, but 15 further divisions into 3, 4, 6, 7, 9, 10, 11, 13, 14, 16, 17, 21, 24, 26, and 27 clusters are possible. The branched and linear taxon dendrite is presented

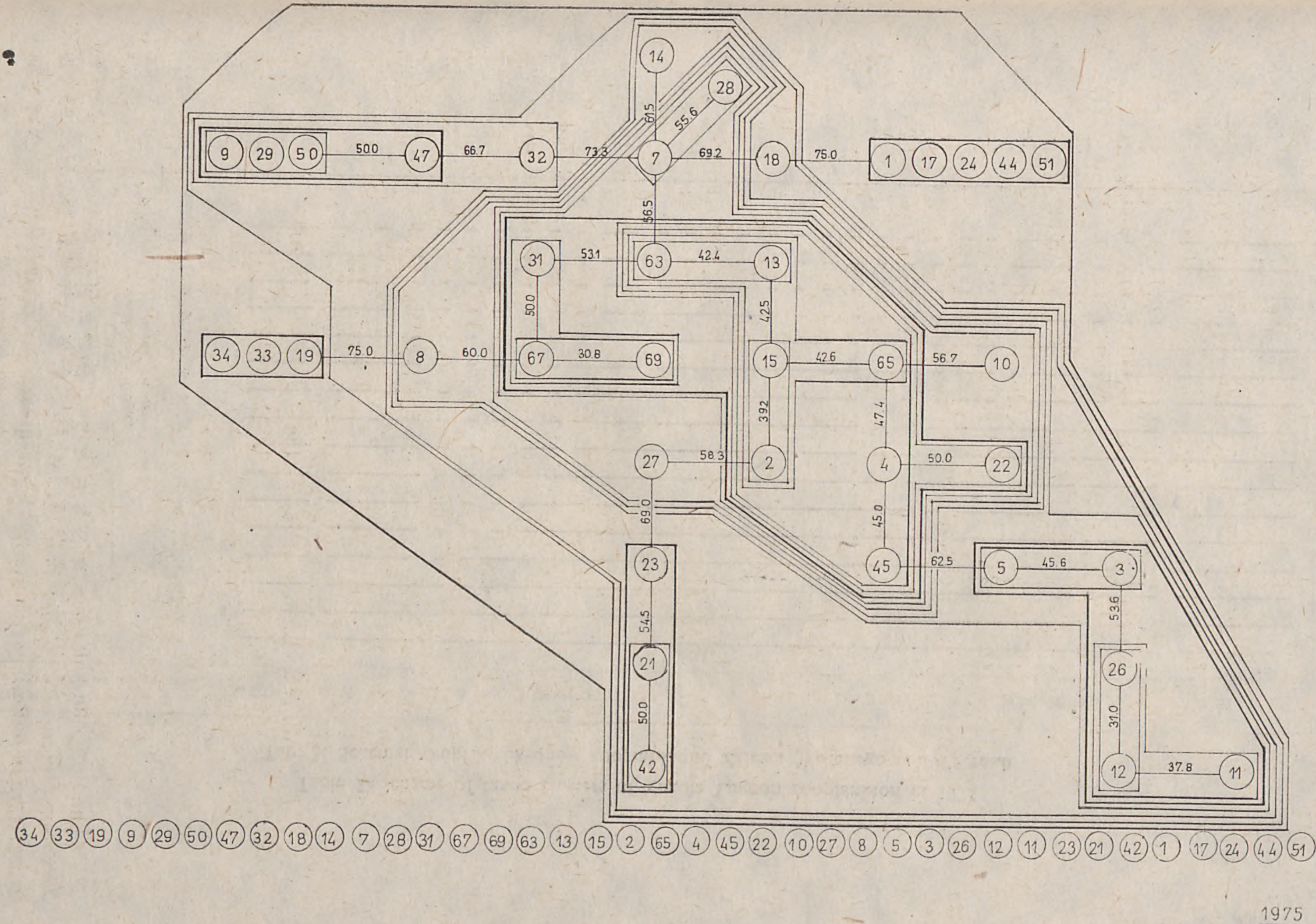
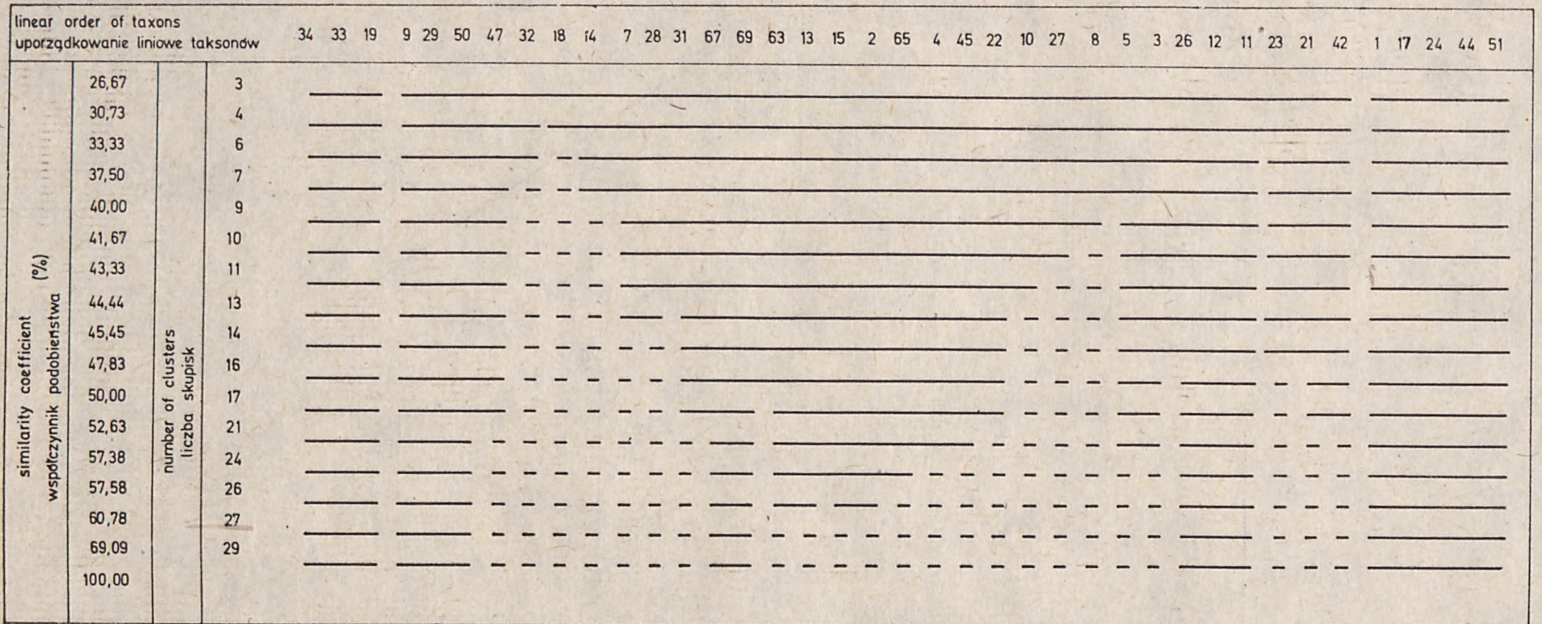


Fig. 3. Dendrite and clusters of 39 zooplankton taxons for the Vistula Lagoon in 1975. Length of segments symbolizing distances in the dendrite are deformed

Rys. 3. Dendryt i skupiska 39 taksonów zooplanktonu Zalewu Wiślanego w 1975 r. Długości odcinków w dendrycie symbolizujące odległości są zniekształcone

Table 3. Scheme of taxon clusters of Vistula Lagoon zooplankton in 1975

Tab. 3. Schemat skupisk taksonów zooplanktonu Zalewu Wiślanego w 1975 roku



in Fig. 3. All possible clusters and their similarity coefficients are presented in Table 3.

1977

r	d	r	d	r	d
75.00		50.00	1.000	42.55	**1.007**
75.00	**1.000**	50.00	1.000	38.28	1.121
72.73	**1.031**	50.00	**1.000**	37.91	**1.010**
66.67	**1.084**	47.77	1.047	33.33	1.137
66.67	**1.000**	47.73	**1.001**	33.33	1.000
62.50	1.067	47.06	1.014	33.33	1.000
61.11	**1.023**	46.50	**1.012**	33.33	**1.000**
52.31	1.168	44.44	1.046	25.00	1.333
51.43	**1.017**	43.75	1.016	25.00	**1.000**
50.00	1.028	43.28	1.011	23.08	**1.083**
50.00	1.000	42.86	1.010	20.00	1.154
50.00	1.000	42.86	1.000		

The taxon dendrite breaks down into 35 clusters, but 13 further divisions into 3, 4, 6, 8, 10, 16, 18, 20, 25, 26, 28, 32 and 34 clusters are possible. The taxon dendrite is shown in Fig. 4. All clusters and their coefficients of similarity have been given in Table 4.

1978

r	d	r	d	r	d
75.00		50.00	**1.000**	44.30	**1.003**
66.67	1.125	50.00	1.000	43.70	1.014
66.67	1.000	50.00	1.000	43.45	**1.006**
66.67	1.000	50.00	1.000	42.86	**1.014**
66.67	**1.000**	50.00	1.000	41.18	1.041
64.29	**1.037**	50.00	1.000	40.00	1.029
60.00	1.071	50.00	1.000	38.89	**1.028**
57.60	1.041	50.00	1.000	37.50	1.035
57.16	1.009	50.00	**1.000**	36.36	**1.031**
56.99	**1.003**	49.09	1.018	33.33	1.091
55.56	1.026	48.65	**1.009**	31.82	1.047
55.56	**1.000**	46.47	1.042	31.25	**1.018**
50.00	1.111	46.31	**1.008**	17.65	1.770
50.00	1.000	44.44	1.042		

The taxon dendrite breaks down into 41 clusters, but a further 12 divisions are possible as follows: 6, 7, 11, 13, 24, 26, 28, 30, 32, 33, 36 and 38 clusters. The branched and linear taxon dendrite is presented in Fig. 5. All possible clusters and their similarity coefficients have been presented in Table 5.

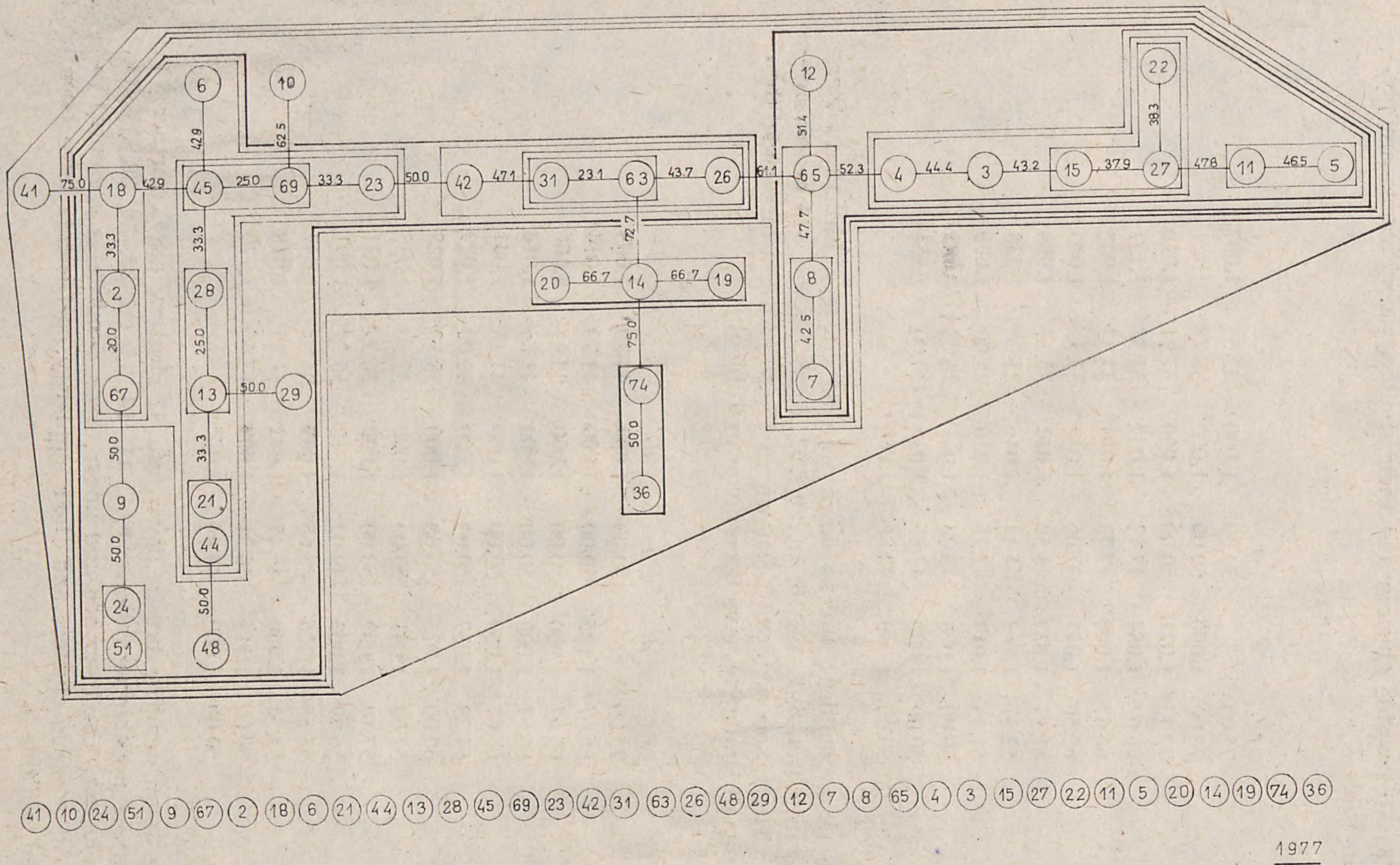
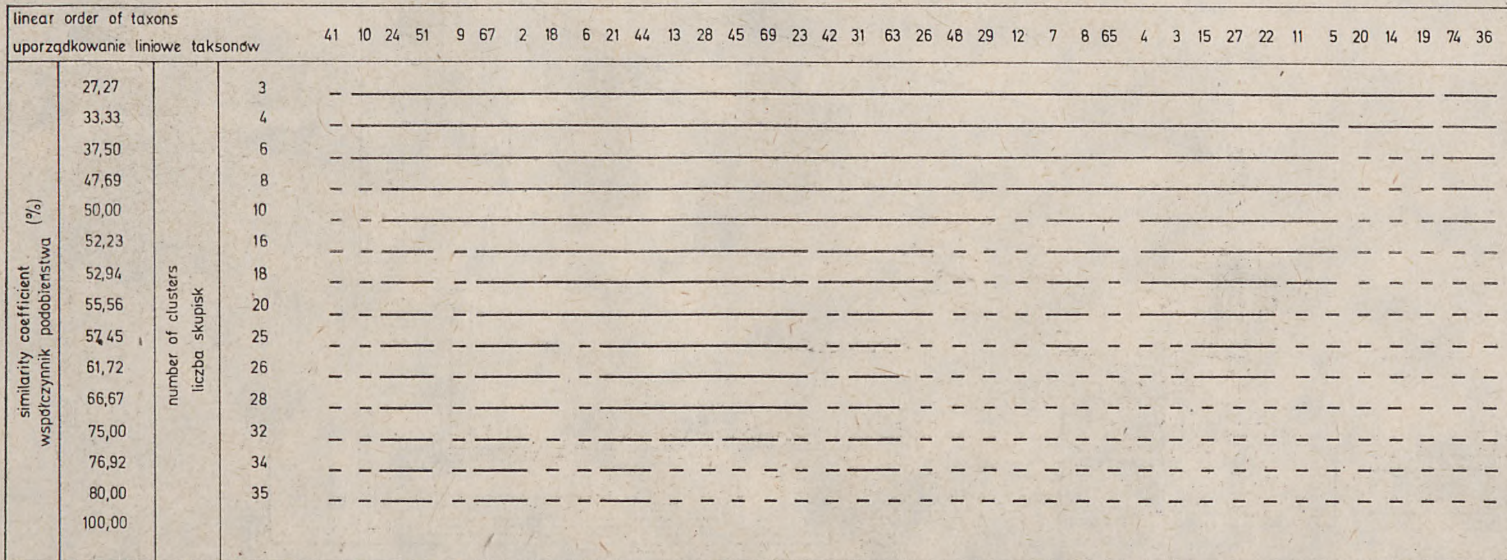


Fig. 4. Dendrite and clusters of 38 zooplankton taxons of the Vistula Lagoon in 1977. Length of segments symbolizing distances in the dendrite are deformed

Rys. 4. Dendryt i skupiska 38 taksonów zooplanktonu Zalewu Wiślanego w 1977 r. Długości odcinków w dendrycie symbolizujące odległości są zniekształcone

Table 4. Scheme of taxons clusters of Vistula Lagoon zooplankton in 1977

Tab. 4. Schemat skupisk taksonów zooplanktonu Zalewu Wiślanego w 1977 roku



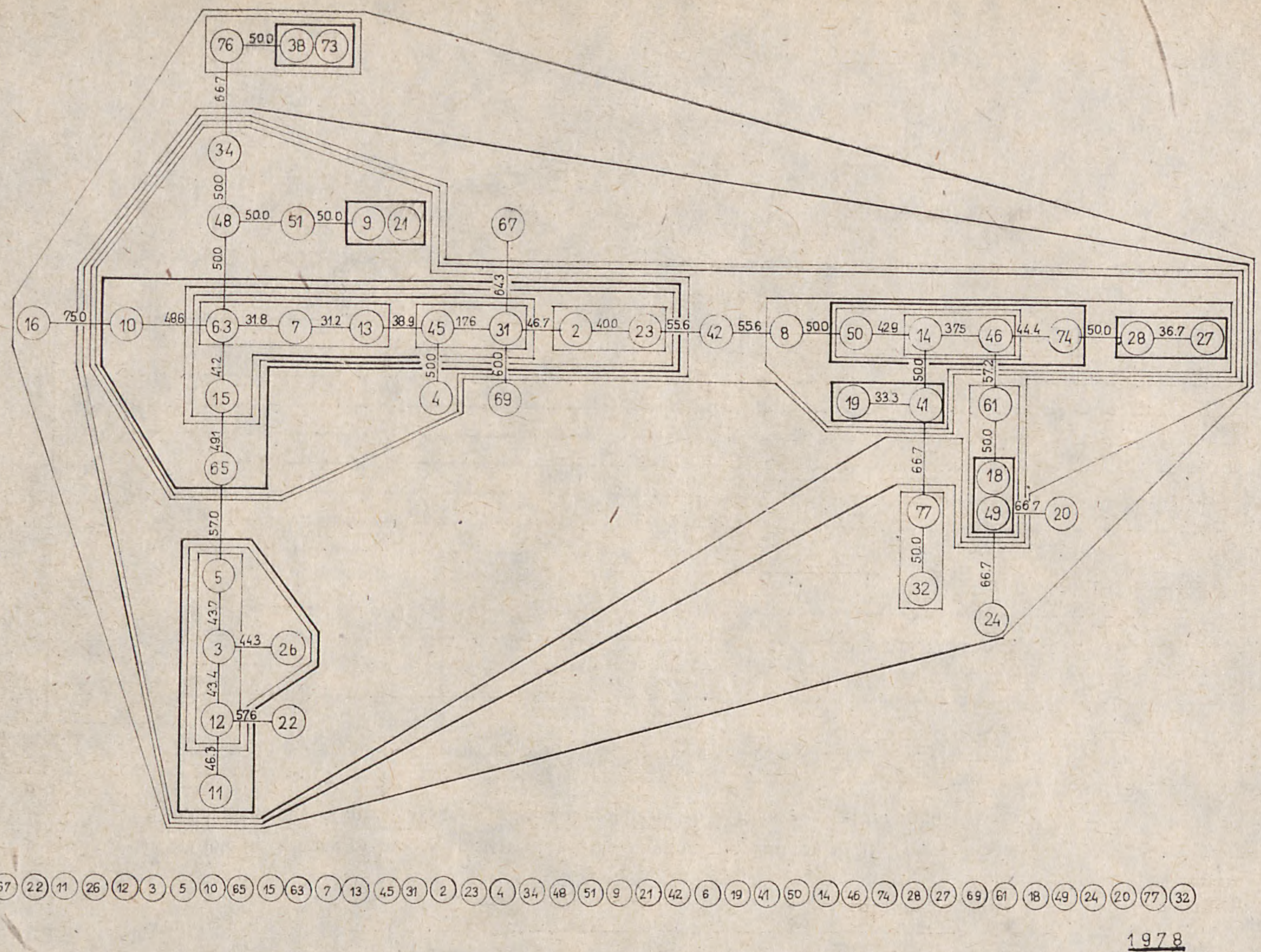


Fig. 5. Dendrite and clusters of 45 zooplankton taxons of the Vistula Lagoon in 1978. Length of segments symbolizing distances in the dendrite are deformed

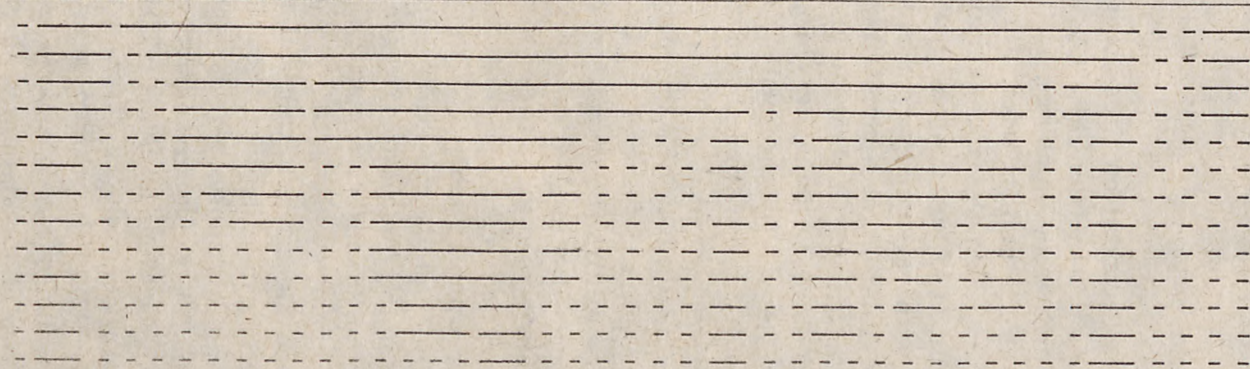
Rys. 5. Dendryt i skupiska 45 taksonów zooplanktonu Zalewu Wiślanego w 1978 r. Długości odcinków w dendrycie symbolizujące odległości są zniekształcone

Table 5. Scheme of taxon clusters of Vistula Lagoon zooplankton in 1978

Tab. 5. Schemat skupisk taksonów zooplanktonu Zalewu Wiślanego w 1978 roku

linear order of taxons / uporządkowanie liniowe taksonów: 16 58 73 76 67 22 11 26 12 3 5 10 65 15 63 7 13 45 31 2 23 4 34 48 51 9 21 42 8 19 41 50 14 46 74 28 27 69 61 18 49 24 20 77 32

similarity coefficient / współczynnik podobieństwa (%)	number of clusters / liczba skupisk
35,71	6
40,00	7
44,44	11
50,00	13
50,11	24
53,33	26
55,56	28
56,30	30
57,14	32
58,82	33
62,50	36
66,67	38
82,35	41
100,00	



4.3. CLUSTERING TENDENCIES OF ZOOPLANKTON

Numbers of zooplankton organisms in the Vistula Lagoon in relation to selected abiotic factors are presented in Tables 6, 7, and 8. The position of stations and taxons depended on linear order of respective branched dendrites (Figs. 2, 3, 4, 5). The tables also give the grouping of aggregations and taxons. Apart from groupings, stations and taxons forming single element clusters are also included. The fields, formed as a consequence of groupings, define the inter-relations for both sets. Results obtained have been discussed for each year separately.

In 1975 stations with various values of environmental factors formed 3 clusters (Fig. 2, Table 2), at a similarity of 59.04%. The strongest grouping, A_1, separated therefrom showed clusters at stations (Table 6). Stations 1 and 3 did not form groupings, but constituted separate clusters, and were characterized by the smallest depth and lowest organic matter index. Station 1 differed from the remaining by the lowest salinity and highest nutrient contents.

Taxons at a similarity of 45.45% formed 14 clusters (Fig. 3, Table 3). Six groupings consisting of several elemnts: A_2, A_3, A_4, A_5, A_6, A_7 (Table 6) were distinguished. The remaining taxons formed single clusters and were not grouped with other taxonomic units.

Grouping A_5, leading as regards the highest number and frequency of occurance at all stations of the Vistula Lagoon, contained euritopic species constituting a compact group of *Brachionus calciflorus* (5), *Brachionus angularis* (3), *Keratella cochlearis* (12), *Filinia longiseta* (11), as also representatives of the *Synchaeta* (26) genus. Grouping A_4 included the largest number of taxons characteristic of brackish waters, and occuring in various numbers. *Pedalia fennica* (22) was the dominant species as regards the highest numbers, and the following taxons constituted components in similarity investigations: *Diaphanosoma brachyurum* (45), *Brachionus calyciflorus* (4), *Asplanchna priodonta* (2), *Keratella cochlearis tecta* (13), *Keratella quadrata* (15), *Eurytemora sp.* (65), *Acartia tonsa* (63), *Mesocyclops leuckarti* (67), *Cyclops sp.* (69).

A_6 grouping of species included three elements of the aggregation: *Bosmina longirostris* (42), *Polyarthra dolichoptera* (21) and *Polyarthra vulgaris* (13). In groupings A_2, A_3 and A_7 a small number of taxons occurred at one or two of the stations with similar environmental conditions. These groupings showed considerable cenologic distance, and at the same time the highest similarity of clustering formed (Fig. 3, Table 3) on a branched dendrite with similarity in taxon numbers. Hence, clusters A_2 and A_7 were formed by taxons sporadically occurring at stations in the Vistula Lagoon, such as: *Ascomorpha saltans* (34), *Cephalodela sp.* (33), *Notholca squamula* (19), also *Lecane luna* (17), *Proales sp.* (24), *Chydorus sphaericus* (44), *Simocephalus vetulus* (51).

Table 6. Number of zooplankton organisms at Vistula Lagoon stations according to linear order of the dendrites in 1975 (in 1000/m³)

Tab. 6. Liczebność zooplanktonu na stanowiskach Zalewu Wiślanego wg uporządkowania liniowego dendrytów w 1975 roku (w tys./m³)

Depth – Głębokość (m)	2,1	2,2	2,9	2.6	3 2	2,6	4,4	3,6	2,8
Salinity – Zasolenie (%)	0,7	2,7	2,5	3,9	3,0	2,9	3,9	3,6	3,9
Nitrates – Azotany (mg N-NO_3/dm³)	0,93	0,74	0,80	0,73	0,69	0,75	0,63	0,77	0,77
Free phosphates – Fosforany wolne (mg PO_4/dm³)	0,357	0,178	0,235	0,238	0,187	0,206	0,183	0,183	0,182
Oxidability – Utlenialność (mg O_2/dm³)	21,7	20,3	25,4	27,8	28,6	28,6	28,6	26,5	27,8

				A_1						
	Stations – Stanowiska / Taxons – Taksony	1	3	2	9	4	5	8	6	7
A_2	34		10							
	33			13						
	19		3	10				3		
A_3	9					10	3			
	29					13				
	50					7				
	47		3			7	7			
	32			15		7	7		15	
	18	10						5		15
	14				13		10	9	8	13
	7	19			7	7	27	23	17	19
	28	15				48	30			28
A_4	31	10	25	20	13	27	17		10	10
	67	30	48	32		38				
	69	13	77	13		23				
	63		27	27	57	27	41	52	51	63
	13	19	30	25	38	46	17	35	16	74
	15	72	16	46	60	33	27	68	38	52
	2	108	8	103	48	12	22	42	18	35
	65	42	139	88	149	136	116	71	101	87
	4	53	187	82	45	64	18	62	24	85
	45	43	280	87	140	90	76	10	21	30
	22	18	132	50	43	46	19	87	41	375
	10	11	110	42	135	60	43	43	7	10
	27	41	7	103		39	38		47	
	8		17	10		13				
A_5	5	554	692	104	72	301	70	9	38	
	3	101	731	216	449	350	70	23	88	42
	26	487	925	269	632	415	435	426	240	623
	12	181	242	306	467	368	338	425	272	585
	11	51	603	431	443	478	533	597	557	314
A_6	23	48	12	12			29			
	21	56								
	42	102		7		7			3	
A_7	1	13		3						
	17	10								
	24	7								
	44	7								
	51	6								

Table 7. Number of zooplankton organisms at Vistula Lagoon stations according to linear order of dendrites in 1977 (in $1000/m^3$)

Tab. Liczebność zooplanktonu na stanowiskach Zalewu Wiślanego wg uporządkowania liniowego dendrytów w 1977 roku (w tys./m^3)

Depth – Głębokość (m)	2,3	2,6	2,9	2,6	2,6	4,7	2,8	3,2	3,5
Salinity – Zasolenie (‰)	0,7	2,2	2,1	2,2	3,0	3,4	3,0	2,5	3,3
Nitrates – Azotany (mg $N\text{-}NO_3/dm^3$)	1,85	0,72	1,12	1,05	0,81	0,58	1,08	1,36	1,35
Free phosphates – Fosforany wolne (mg PO_4/dm^3)	0,215	0,193	0,225	0,185	0,251	0,160	0,157	0,229	0,229
Oxidability – Utlenialność (mg O_2/dm^3)	27,5	27,0	$26,0^{b}$	26,3	25,1	24,0	23,5	26,0	25,8

	Stations – Stanowiska / Taxons – Taksony		B_1			B_2				
		1	5	2	3	9	8	7	4	6
	41		9			3				41
	10	10	3	70	25		3	10	19	
B_3	24			5						
	51	3		7						
	9	3		6	7					
	67	11	11	7	7					
	2	13	7	10	8	4	3	5	3	10
	18	8	5	3	6			4	10	5
	6	21	17		3				8	
	21	13		8						
	44	7		5						
	13	11	4	8		3	3		7	
	28	20		7					5	
	45	19	11	6	7	4	3	4	8	
	69	17	12	30	7				8	3
	23	22	3	23	8			3	5	6
	42	35	9	22	24	3	9		35	8
	31	9	6	16	11	6	8	13	15	17
	63	7	23	16	20	13	29	29	27	43
	26		25	17	19	19	16	22	9	9
	48	8								
	29			12		3	7		7	
B_4	12	50	65	35	31	170	65	54	31	171
	7		10	58	8	100	114	112	13	23
	8	14	10	13	12	62	79	68	33	28
	65	33	86	78	78	42	120	61	72	80
	4	72	36	102	86	43	27	11	93	92
	3	83	211	77	84	17	93	91	150	135
	15	57	57	70	138	89	111	133	132	274
	27	51	115	130	146	111	158	176	209	378
	22	35	114	126	67	170	176	371	459	824
	11	30	73	80	196	217	449	264	98	212
	5	315	42	76	42	64	352	249	190	[illegible]
	20						3	5		
	14		7			6	4	7		4
	19		7							
B_5	74					7	3			7
	36									5

Table 8. Number of zooplankton organisms at Vistula Lagoon stations according to linear order of dendrites in 1978 (in $1000/m^3$)

Tab. 8. Liczebność zooplanktonu na stanowiskach Zalewu Wiślanego wg uporządkowania liniowego dendrytów w 1978 roku (w tys./m^3)

Depth – Głębokość (m)	2,3	2,2	3,0	2,7	2,9	3,4	3,6	2,8	4,6
Salinity – Zasolenie (‰)	1,4	2,7	3,0	3,1	3,0	3,5	3,6	3,5	3,7
Nitrates – Azotany (mg $N\text{-}NO_3/dm^3$)	0,73	0,46	0,58	0,26	0,33	0,51	0,27	0,31	0,40
Free phosphates – Fosforany wolne (mg PO_4/dm^3)	0,124	0,123	0,152	0,195	0,169	0,132	0,121	0,107	0,110
Oxidability – Utlenialność (mg O_2/dm^3)	24,0	28,2	27,4	24,0	24,4	26,9	27,6	26,5	26,6

			C_1					C_2		
	Stations – Stanowiska Taxons – Taksony	1	3	4	5	3	6	9	7	8
	16									26
C_3	38			5						
	73		3	7						3
	76		7	10					3	3
	67		6	25	16	7				
	22	14	21	23		16	66	143	187	143
C_4	11	22	321	321	319	327	352	195	276	276
	26	159	150	288	91	23	176	51	29	196
	12	54	152	102	150	105	177	198	156	237
	3	180	204	131	196	191	158	85	52	92
	5	23	191	106	89	65	49	86	105	105
C_5	10		25	61	23	50	14	17	29	122
	65	53	70	102	377	80	85	75	77	67
	15	28	36	28	9	20	40	42	44	70
	63	3	25	39	46	17	39	54	60	138
	7		12	15	12	13	17	17	26	31
	13		12	8	18	10	8	13	17	26
	45	22	22	17	18	20	11	18	15	15
	31	22	22	24	20	20	11	10	9	7
	2	20	17	10	10			18	3	11
	23	15	22	8			3	10	10	
	4	22	48	32	53		11	18	3	7
	34		7			7	3			
	48					7				
	51	7				7				
C^6	9	7								
	21	7								
	42	7	18.	4	8	9			11	
	8		30	3		8		11	12	12
C_7	19		10						7	3
	41		7		8		7		7	

Table 8 – continued

C_8	50		15				7	7		5
	14		7				7	7	11	18
	46	3	10	24			7	7	7	12
	74	3	25	82			16	3		11
C_9	28	10	43	28						
	27	33	33	36						
	69	21	13	8	10	48	40			
	61			7			11			7
C_{10}	18		3	8				7		10
	49	3		9				7		12
	24		3					7		7
	20									7
	77						10			
	32			3	10		10		3	

In 1977, similarity analyses of the numbers of zooplankton organisms at stations with different hydrological values showed that three clusters formed at a similarity level of 51.44% (Fig. 2, Table 2). Two of these, being multi-elemental clusters, are indicated in Table 7 by the symbols B_1 and B_2. A third independent cluster was at station 1, located in the south-western part of the Vistula Lagoon.

Stations 2, 3 and 5, where salinity and value of organic matter were similar, formed grouping B_1. Stations 4, 6, 7, 8 and 9, with a higher level of salinity, formed grouping B_2.

Eight clusters were formed as a result of numerical similarity analyses of taxons, at a similarity of 47.69% (Fig. 4, Table 4). Here, three groups were distinguished, denoted B_3, B_4, B_5. The remaining taxonomic units occurred as independent clusters and on analyzing the similarity coefficient did not form groupings.

The strongest clustering was that of 11 taxons with very high numbers and denoted as B_4. Brackish water taxons, such as *Pedalia fennica* (22), *Eurytemora sp.* (65) and eurotopic species were characteristic of this grouping: occurring at all the stations in the Vistula Lagoon. More taxonomic units were found in grouping B_3, but their numbers were not as high as in grouping B_4. Both brackish and freshwater species occurred here. Grouping B_5 was made up of two species, *Acartia bifilosa* (74) and *Synchaeta oblonga* (36), found at stations 6, 8 and 9. Single clusters were formed of *Bosmina coregoni maritima* (41), *Keratella cruciformis* (14), which occurred at stations with a higher level of salinity, and sporadically *Notholca striata* (20).

Assuming a numerical similarity coefficient of 60.65% for stations in 1978, the dendrite divides into four clusters (Fig. 2, Table 2). Stations 1 and 8 with different environmental conditions formed single clusters (Table 8). The separate grouping C_1 was formed from five stations (2, 3, 4, 5, 6), whereas grouping C_2 — from only two (7 and 9).

The similarity dendrite for taxon numbers formed 24 clusters at a coefficient of 50.11% (Fig. 5, Table 5). Eight multi-element groupings denoted in Table 8 by the symbols C_3, C_4, C_5, C_6, C_7, C_8, C_9, and C_{10} were isolated from these. The remaining clusters were formed of single taxons and did not form groupings with other taxonomic units at the accepted similarity coefficient.

The strongest grouping denoted by the symbol C_4 was a compact group of taxons with high numbers occurring at all the stations. The greatest number of aggregation elements was concentrated in grouping C_5, mostly taxons characteristic of brackish waters (Table 8). C_3, C_6, C_7, C_9 and C_{10} were the smallest groupings consisting of two species each, with very low numbers. Grouping C_8 was made up of four species — *Sida cristallina* (50), *Evadne nordmanni* (46), *Keratella cruciformis* (14), and *Acarta bifilosa* (74) characteristic of sea water.

5. DISCUSSION OF RESULTS

On the basis of three-year investigations of a synthetic character, the results of which are presented in Tables 6, 7, 8, it can be concluded that the process of forming clusters constitutes an expression of the flexible reaction of zooplankton to environmental conditions. The various number of clusters (Table 2, 3, 4, 5), both of stations grouping and taxons, indicate that the tendency for zooplankton to form clusters is not obligatory, but depends upon the relations existing between species and environment. These relations are not constant, especially for stations 2, 3, 4, 5, 6 (Fig. 1). These stations are located in the central region of the Vistula Lagoon, where salinity ranges from 2.1‰ to 3.5‰ (Tables 6, 7, 8).

During the three-year period of investigations, station 1 situated in the south-western part of the Vistula Lagoon always formed a separate cluster, differing from the remaining groupings as regards numbers, species composition and number of taxons. On the basis of examples for selected environmental factors it can be seen that not only did salinity decide as to the individual character of this region, but also a combination of other features such as smallest depth, and above all, the high content of nitrates [10, 11].

Groupings at stations also differ from each other as regards common taxons. The highest number of common taxons was in grouping B_1, where the dominant species, as far as numbers were concerned, was *Brachionus angularis* (3), whereas *Filinia longiseta* (11) and *Synchaeta litoralis* (27) were components.

Tables 6, 7, 8 also show relationships between the particular taxon groupings of the Vistula Lagoon. These relationships run in two directions and are based on either eurytopic species occurring at all stations in the Vistula Lagoon, and hence without any decisive significance as regards groupings of stations, or on taxons requiring definite and specific environmental factors spacially distributed, such as salinity, water depth, nutrients. On the whole these species consist of taxons characteristic for fresh or salt water, and forming single clusters. However, under no circumstances do such species occur in large numbers in environments untypical to them, and in such cases give way to brackish water taxons or eurytopic species which determine the occurrence of zooplankton groupings as regards numbers and stability.

The process of forming clusters, as shown by an analysis of similarity based on numbers of zooplankton organisms, is not schematically distributed in the spacial system of the Vistula Lagoon stations. This would indicate that clusters can form not only as a result of biotopic and biocenotic factors, but that groupings of seasonal dominants can also form as changes take place in diagnostic properties.

6. CONCLUSIONS

The theoretical generalization of the results of cluster analysis of zooplankton, based on populations of taxons in their spatially determined variability, constitutes the basis for the following conclusions:

1. Station 1, situated in the south-western region of the Vistula Lagoon, differed basically from the remaining stations as regards zooplankton numbers, species composition, abiotic factors, and constituted an individual cluster during the period of investigations.

2. Groupings (A_1, B_1, B_2, C_1, C_2) or single clusters were formed at stations depending upon the relations between the composition and number of taxons, and abiotic factors of the environment.

3. Zooplankton groupings resulting from similarity of number of taxons can be divided as follows:

groupings (A_5, B_4, C_4) of taxons occuring at all stations in the Vistula Lagoon, made up principally of eurytopic species which — although they do not qualify the biotope — are nevertheless characteristic of eutrophic water due to their very high numbers.

groupings (A_3, A_4, A_6, B_3, B_5, C_5, C_7, C_8, C_9, C_{10}) or single clusters of permanent taxons of various numbers, made up principally of euryhaline fresh and brackish water species,

groupings (A_2, A_7, C_3, C_6) or single clusters of taxons occurring sporadically at specific stations in the Vistula Lagoon.

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ANALIZA SKUPIEŃ LICZEBNOŚCI ZOOPLANKTONU ZALEWU WIŚLANEGO

Streszczenie

Praca niniejsza oparta jest na trzyletnich materiałach zooplanktonu Zalewu Wiślanego, zebranych w marcu — listopadzie 1975 r., maju — listopadzie 1977 r i lutym — listopadzie 1978 r. Próby pobierano w tych latach co miesiąc z tych samych dziesięciu stanowisk; pięć z nich (stan. 1, 2, 4, 6, 8) leżało na podłużnym przekroju Zalewu, a cztery (stan. 3, 5, 7, 9) — na przekrojach poprzecznych (rys. 1). Próby pobierane były czerpakiem Ruttnera. Badania mikroskopowe przeprowadzono w komorze o pojemności 1 cm^3. Ogółem zebrano i poddano analizie mikroskopowej 512 prób (Tab. 1).

Celem pracy była analiza skupisk zooplanktonu na podstawie liczebności opierając się na definicji podobieństwa i odległości [7, 8, 9]. Stopień podobieństwa wyrażono przy pomocy wzoru Marczewskiego i Steinhausa [8]:

$$S=\frac{w}{a+b-w}.$$

Budowę dendrytów i sposób ich liniowego uporządkowania oparto na analizie podobieństw, przy założeniu zachowania jak najkrótszych odległości (rys. 2, 3, 4, 5). Dla zbioru stanowisk wydzielono zgrupowania wynikające z podobieństw liczebności występującego na nich zooplanktonu, natomiast dla zbioru taksonów, zgrupowania wynikające z podobieństw ich liczebności. Wszystkie możliwe skupiska stanowisk i taksonów w trzyletnim okresie badań przedstawiono w postaci schematów w tab. 2, 3, 4, 5.

Obliczenia współczynników podobieństw wykonano elektroniczną maszyną cyfrową „Odra-1204".

W analizie tendencji skupiskowych zwierząt planktonowych uwzględniono tylko jednostki taksonomiczne w randze systematycznej rodzaj — gatunek, zgodnie z założeniami Romaniszyna [9].

Wyniki badań zebrane zostały w tab. 6, 7, 8. Symbolami: A_1, B_1, B_2, C_1, C_2 zaznaczono zgrupowania stanowisk wynikające z podobieństw liczebności zooplanktonu. Zgrupowania gatunków wynikające z podobieństw ich liczebności zaznaczono symbolami: A_2, A_3, A_4, A_5, A_6, A_7, B_3, B_4, B_5, C_3, C_4, C_5, C_6, C_7, C_8, C_9, C_{10}. W tabelach tych uwidocznione są również powiązania poszczególnych zgrupowań taksonów Zalewu Wiślanego. Powiązania te przebiegają w dwu kierunkach i opierają się bądź na gatunkach eurytypowych, występujących na wszystkich stanowiskach (a więc nie mających decydującego znaczenia przy zgrupowaniu stanowisk, ale ze względu na bardzo wysoką liczebność i masowe pojawy są charakterystyczne dla wód eutroficznych), bądź też na taksonach wymagających określonych, specjalnych czynników środowiska w rozmieszczeniu przestrzennym, jak zasolenie, głębokość, sole biogeniczne. Analiza podobieństw na tle liczebności zooplanktonu wykazała, że proces tworzenia się skupisk nie jest schematycznie rozmieszczony w układzie przestrzennym stanowisk Zalewu Wiślanego. Różna liczba

skupisk, zarówno zgrupowań stanowisk, jak i taksonów, wskazuje na to, że właściwości zooplanktonu do wytwarzania zgrupowań nie są obligatoryjne, ale zależą od układu stosunków między gatunkami a środowiskiem.

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