DYNAMICS OF PHYTO- AND ZOOPLANKTON COMMUNITIES DIVERSITY OF THE SFÂNTU GHEORGHE ARM UNDER THE ANTHROPOGENIC IMPACT

LAURA PARPALĂ, MIRELA MOLDOVEANU, ALINA DUMITRACHE, LARISA FLORESCU

During 1983-1989 important hydrotechnical works were performed in Sfântu Gheorghe arm to improve the shipping, after these interventions resulting three different systems: natural sectors, meanders, canals. These changes proved later to be one of the most aggressive anthropogenic actions in the area. Our research was carried out during 2008-2010 in aims to assess the systemic response of biocoenosis to the human impact in Sfântu Gheorghe branch. The similarity of the phyto- and zooplankton structure was tested by Bray-Curtis analysis. The results show that the years 2008 and 2010 are similar in high percentages in terms of zooplankton species richness (86.39%), while the years 2009 and 2010 are similar (94.14%) for phytoplankton species richness. Phytoplankton and zooplankton diversity and densities were measured using diversity indices (species richness, Shannon-Wiener, Simpson and Evenness) and then correlated to environmental parameters using canonical correspondence analysis. Under the new configuration, sectioned meanders suffer a slow ecological succession to the lentic ecosystem type, favorable for aquatic flora and fauna development.

Key words: environmental parameters, species richness, spatial distribution, multivariate analysis, similarity indices.

INTRODUCTION

The Danube, the second largest river in Europe after the Volga, forms an important delta at the pouring mouth of the river into the Black Sea. The Danube Delta is a young region formed by terrestrial, wetlands, lentic and lotic ecosystems, a very favourable place for the development of a highly ecological diversity (Oosterberg *et al.*, 2000). These characteristics make it the most dynamic complex of ecosystems in the European continent and also part of Biosphere Reserve (Tudorancea & Tudorancea, 2006).

Along the Danube Delta, Danube splits in three main branches: Chilia, Sulina, and Sfântu Gheorghe. Sfântu Gheorghe branch, the oldest branch of the Danube, marks the southern side of the delta and has transported over time 21-25% of water and sediment into the Black Sea (Almazov *et al.*, 1963; Popa 1997; Gâştescu & Ştiucă, 2006).

In order to facilitate the shipping transport, some corrections were required of the meander structure in all the three main branches of the Danube. Thus, during 1980s a very large programme of the Danube Delta transformation was implemented. Under the impact of this project, the meander belts of Sfântu Gheorghe were cut-off, so its length was shortened from 108 km to 70 km (Gâştescu, 1996).

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The anthropogenic intervention led to the formation of three distinct areas on the arm: natural sectors (the reference areas), meanders and canals. Each of the three areas has undergone significant geomorphological and hydrological changes and also the biocenoses of these ecosystems, under interactions between hydrological events and physical-chemical traits, acquire different structural and functional characteristics.

The hydrotechnical works carried out along the River Danube and its tributaries as well as within the Danube Delta have significantly influenced the river water and sediment discharge and consequently the particle flux in the North-Western Black Sea (Popa *et al*., 1995; Popa, 1997).

Comparing with lentic systems, the species composition and community structure of phyto- and zooplankton in lotic habitats are still poorly understood (Basu & Pick; 1996; Naichengwu *et al*., 2011). The spatial and temporal distribution patterns of a community are very important for understanding the ecosystem functioning, because they can affect the ecological processes and stability and reflect major shifts in environmental conditions (Suikkanen *et al.*, 2007).

The purpose of this paper is to highlight the response of phyto- and zooplankton communities diversity to natural and anthropogenic control factors in the three types of ecological systems, and to update the existing database (Brezeanu & Prunescu, 1962; Brezeanu *et al*., 1966); Zinevici & Teodorescu, 1989 a, b; Popescu-Marinescu *et al*., 1990).

MATERIAL AND METHODS

THE STUDY SITE

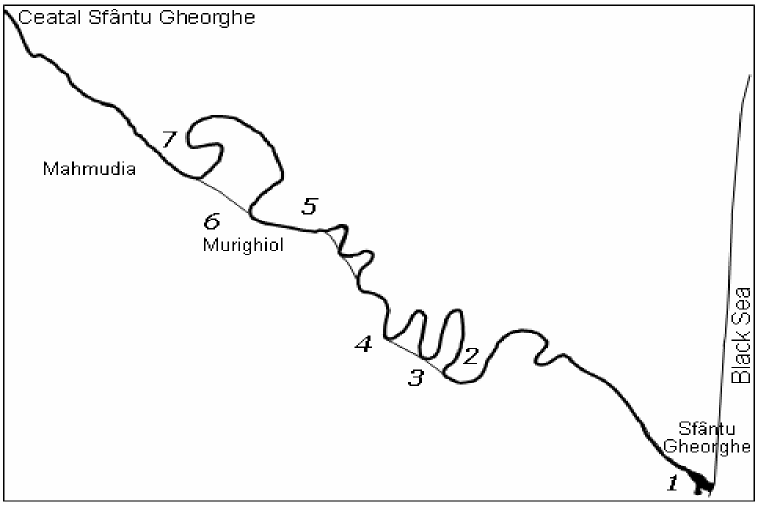

Fig.1. The schematical representation of Sfântu Gheorghe arm of sampling point.

Sfântu Gheorghe branch (44°53'984''N - 29°34'660''E and 45°05'795'' N - 29°04'885''E) starts from Ceatal Sfântu Gheorghe, km 108.8 and is formed by natural sectors, canals and cut off meanders.

SAMPLING AND DATA PROCESSING

The samples were taken seasonally during 2008-2010, covering all the three types of ecosystems, from 7 transects, with coastal and medial sampling points (Fig. 1).

Phytoplankton and zooplankton sampling was performed using a Patalas-Schindler (5 liters) device on water column. The phytoplankton conservation was made in 500 ml plastic containers, with 4% formaldehyde solution. In the laboratory, phytoplankton samples were concentrated by sedimentation and filtration, using an Ø 65 mm network (Vollenweider, 1969; Britton and Greeson, 1987). The identification of phytoplankton species and abundance was made using a Zeiss inverted microscope according to Utermöhl (1958).

Zooplankton samples were collected by filtering 50 liters of water through an Ø 65 mm mesh network and preserved with 4% formaldehyde solution. The density (ind L^{-1}) was assessed by microscopic methods, using a Zeiss reversed microscope type, by direct counting into a Kolwitz chamber (Utermöhl, 1958). The species with a frequency index between 50-100% were considered constant species.

The water samples for physical-chemical analysis were collected on water column, from medial and coastal points, with a Patalas-Schindler device.

The transparency was determined with a Secchi disk; the depth was measured with a sonar; the temperature, pH, conductivity, salinity, dissolved oxygen content were measured in the field with a multiparameter WTW 340 i (Germany). Samples for chemical analyses were frozen for further analyses in the laboratory. Nutrients were determined spectrophotometrically: NH_4^+ - as yellow compound with Nessler reagent, NO_2^- – as red compound with sulphanilic acid and α-naphthylamine, NO_3^- – as yellow compound with sodium salicylate (Tartari & Mosello, 1997), total reactive phosphorus (TRP) - as blue phosphomolybdate, reduced by ascorbic acid, total phosphorus (TP) - by oxidation with potassium peroxodisulphate (Tartari & Mosello, 1997); the organic matter content was estimated from the chemical oxygen demand determined by oxidation with $K_2Cr_2O_7$ (COD-Cr).

Statistical analyses were performed using SPSS 15.0 Windows Evaluation Version, available for download at http://www.spss.com. and BioDiversity Pro available for download http://www.sams.ac.uk/research/software.

The phyto- and zooplankton abundance was used for diversity indices calculation: Shannon Wienner, Simpson diversity and species Evenness. The spatial and temporal distribution of biotic parameters among the Sfântu Gheorghe branch characterized the structure of phyto- and zooplankton assessed by analysis of variance, a one-way ANOVA and Bray-Curtis similarity analysis.

The results obtained during the study period for the environmental variables and the species composition of phyto- and zooplankton were subjected to a CCA (canonical correspondence analysis) after Ter Braak (1986, 1995) to examine the relationships between them. In order to determine the variables best related to the phytoplankton and zooplankton dynamics during the three-year study, a Monte Carlo permutation test was applied.

RESULTS

ENVIRONMENTAL CHARACTERISTICS

The distribution of phyto- and zooplankton communities is in a close relationship with environmental factors (Naichengwu, 2011). In Sfântu Gheorghe branch the physical-chemical parameters varied widely in the three studied areas (Table 1). For example, the depth mean ranged from 11.80 m in canals to 3.41 m in meanders, pH mean ranged from 8.53 in canals to 8.29 in meanders. The O_2 mean ranged from 8.16 mg/L in canals to 7.27 mg/L in natural sectors. NO_2 mean ranged from 0.10 mg N/L in sectors to 0.02 mg N/L in canals and meanders while TP ranged from 87 µg/L in meanders to 79.66 µg/L in sectors. TOC mean ranged from 8.89 mg C/L in meanders to 6.50 mg C/L in canals.

Table 1
The dynamics of physical-chemical parameters

Parameters	S	M	C	S	M	C	S	M	C
	2008			2009			2010		
Depth (m)	6	4.43	11	6.4	2.3	13	6	3.5	11.3
Transparency (m)	0.54	0.53	0.5	0.5	0.5	0.4	0.5	0.5	0.5
Temperature (Cº)	22.9	17.7	18.3	17.8	17	17.2	20	18.5	18.5
pH	9.01	8.7	9.2	8	8	8.2	8.1	8.17	8.2
Conductivity	429	433	423	261	257	253	450	437	455
Salinity	0	0	0	0	0	0	0	0	0
O_2 (mg O_2/L)	7.42	7.07	7.3	7.2	8.5	8.6	7.2	8.1	8.59
Sat.O_2 (%)	77.3	66.7	75.6	88	85	89	77	85.5	90.3
Redox	-155	-85	-113	-35	-44	-41	-75	-78	-77
CCO-Cr (mg C/L)	19.4	22	17.03	23	24	16.3	21	24.8	18.9
TOC (mg C/L)	7.61	8.27	6.5	8.4	9.1	5.9	7.7	9.3	7.1
NH_4 (mg N/L)	0.35	0.30	0.5	0.34	0.46	0.37	0.21	0.21	0.16
NO_2 (mg N/L)	0.28	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
NO_3 (mg N/L)	0.71	0.9	0.8	1.6	1.8	1.9	1.6	1.7	1.6
DIN (mg N/L)	1.09	1.3	1.3	2	2.2	2.5	1.9	1.9	1.8
PO_4 (µg/L)	50	54	60	41	38	42	53	63	53
org-P (µg/L)	20	22	18	53	55	61	25	30	23
TP (µg/L)	75	77	78	85	92	102	79	92	76

S = Natural sectors; M = Meanders; C = Canals

PHYTOPLANKTON COMMUNITY

Taxonomical investigations on Sfântu Gheorghe phytoplankton highlight the presence of three dominant groups: Bacillariophyceae, Chlorophyceae and Cyanobacteria. The groups Euglenophyceae, Chrysophyceae and Xanthophyceae had negligible contribution to the phytoplankton community. In the canals 102 species were recorded, compared to 136 found in the natural sectors.

A similar decreasing trend in the number of species in impacted areas was found in seasonal dynamics. Overall, the number of recorded species richness had a maximum in spring (54 species) in natural sectors, remained unchanged in summer and in autumn a diminishing (14 species) occurred, in canals (Fig. 2).

Shannon diversity index varies between 4.05 (spring 2009) in natural sectors and 1.99 (autumn 2009) in canals (Fig. 3).

Evenness values of phytoplankton during the study period varied in a narrow range, from 0.70 (recorded in meanders in autumn 2008) to a 0.89 (in natural sectors in autumn 2010) (Fig. 4).

ZOOPLANKTON COMMUNITY

During the study, the taxonomical composition of zooplankton communities was formed by 176 species, belonging to six groups, the highest percent being held by Rotifera (47.16%), followed by Testacea (19.32%), Ciliata (15.91%), Cladocera (10.80%), Copepoda (6.25%) and Lamellibranchia (0.57%).

Seasonal dynamics indicates high species richness in summer in meanders (73 species) and natural sectors (65 species) and in spring in canals (53 species). Annual variation is generally in a downward trend from 2008 to 2010. The maximum was found in meanders, in 2008 (76 species), while the minimum in canals in 2010 (49 species) (Fig. 5).

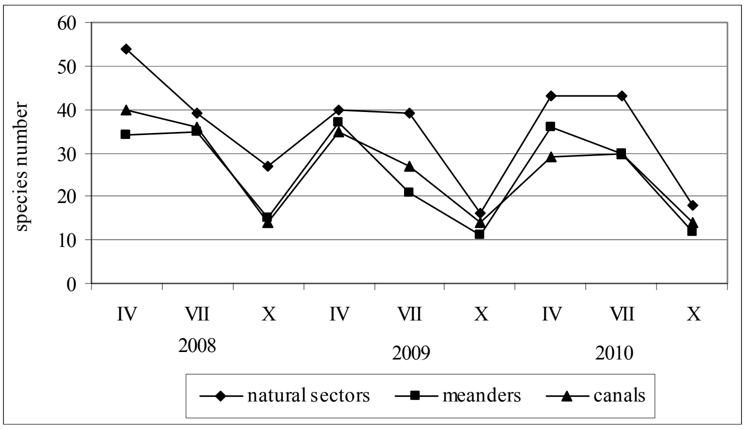

Fig. 2. Phytoplankton species richness in Sfântu Gheorghe branch (2008-2010).

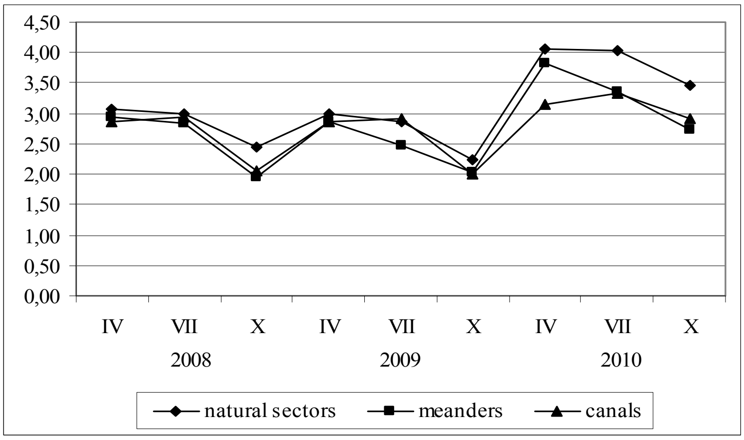

Fig. 3. The dynamics of Shannon diversity of phytoplankton in Sfântu Gheorghe branch (2008-2010).

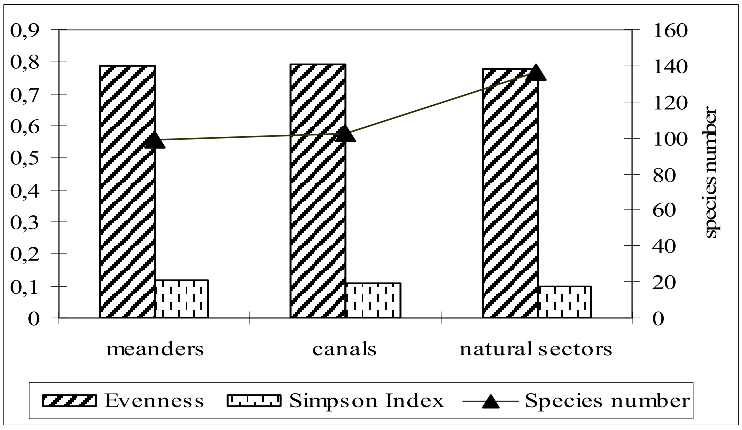

Fig. 4. The diversity indices of phytoplankton community in Sfântu Gheorghe branch (2008-2010).

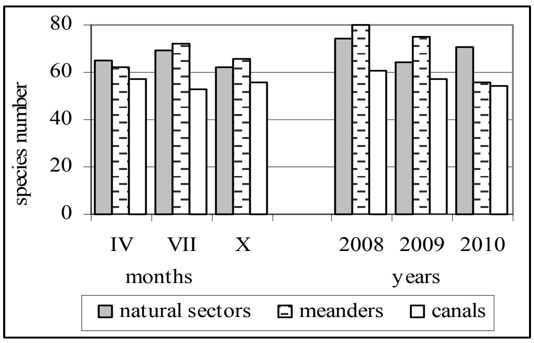

Fig. 5. Zooplankton species richness in Sfântu Gheorghe branch (2008-2010).

Shannon diversity index shows both the maximum (3.200 in summer) and the minimum (2.566 in autumn) in canals. The annual dynamics recorded in 2010 the highest value in natural sectors (3.160) and the lowest (2.320) in 2009, in canals (Table 2).

The seasonal distribution of individuals among species is relatively uniform, the evenness showing high values, ranging between 0.716 (in summer and autumn in natural sectors) and 0.643 (in spring in meanders). In the annual dynamics, the maximum (0.816) and minimum (0.596) were found in meanders, in 2010, respectively in 2008 (Table 3).

Table 2

Seasonal and annual dynamics of zooplankton Shannon-Wiener diversity index during 2008-2010

Seasons	S	M	C
IV	3.003	2.796	2.673
VII	3.153	2.863	3.200
X	2.850	2.760	2.566

Years	S	M	C
2008	3.156	2.740	2.693
2009	2.690	2.523	2.320
2010	3.160	3.156	2.886

Table 3

Seasonal and annual dynamics of zooplankton evenness during 2008-2010

Seasons	S	M	C
IV	0.656	0.643	0.646
VII	0.716	0.666	0.653
X	0.716	0.710	0.710

Years	S	M	C
2008	0.696	0.596	0.666
2009	0.626	0.606	0.600
2010	0.766	0.816	0.743

Results from CCA ordination of phytoplankton groups and environmental variables (Fig. 6) led to the conclusion that nutrients, mainly organic P, NO_2 (-0.35, -0.35), temperature, transparency and pH were correlated with the first CCA axis (0.31, 0.48 and 0.41). The temperature, NO_2 and PO_4 were the most correlated (0.30, 0.66 and 0.38, respectively) with the second axis. These two axes alone explained 86.6% of the total phytoplankton variance.

Results from CCA ordination of zooplankton groups and environmental variables (Fig. 7) led to the conclusion that nutrients (mainly TP, organic P, NO_2) (-0.34, 0.30, 0.24), pH, temperature, transparency (-0.29, -0.24, -0.16 respectively) were correlated with the first CCA axis while transparency, TOC and NH_4 were the most correlated (0.15, -0.29 and 0.13, respectively) with the second axis. These two axes alone explained 71.5% of the total zooplankton variance.

DISCUSSION

The three systems of Sfântu Gheorghe branch are characterized by different dynamics of ecological parameters of each area.

The relationship between measured environmental variables and phyto-zooplankton assemblages of the ecosystem was explored using canonical correspondence analysis (CCA). CCA is useful for identifying which environmental variables are important in the determination of community composition as well as of spatial variation in the communities (Black *et al.*, 2004).

The multivariate analysis results indicate that phytoplankton assemblage was highly correlated with nutrient concentrations (particularly phosphorus and NO_2), transparency, but also with temperature and pH.

From the point of view of the relationship between environmental factors and dynamics of phytoplankton composition being established, Chlorophyceae and Cyanobacteria are correlated mainly with temperature, pH, transparency and PO_4, while Bacillariophyceae are influenced by DIN, NH_4, PO_4, TP, O_2.

The remote location of Xanthophyceae, Chrysophyceae and Euglenophyceae groups can confirm these groups have a low number of species in the whole phytoplankton community (Fig. 6).

The multivariate analysis indicates that zooplankton community was highly correlated with nutrient concentrations (particularly P and NO_2), TOC, but also with transparency and pH. From the point of view of the relationship between control factors and zooplankton composition being established, the correlation of Rotatoria is positive with depth, NO_3, PO_4 and inverse with the TOC, NO_2 and TP, while Copepoda and Cladocera are positively correlated with temperature and pH, transparency and inverse with NH_4 and O_2 (Fig. 7).

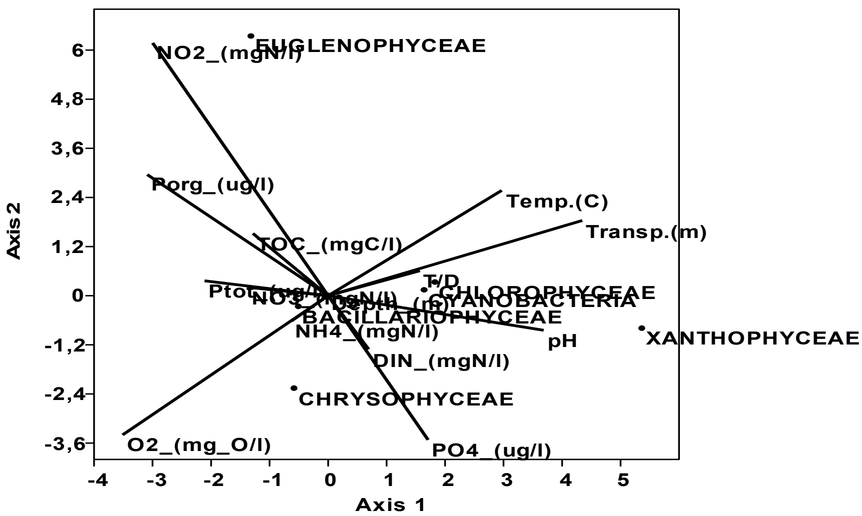

Fig. 6. The ordination (CCA) for phytoplankton and environmental parameters.

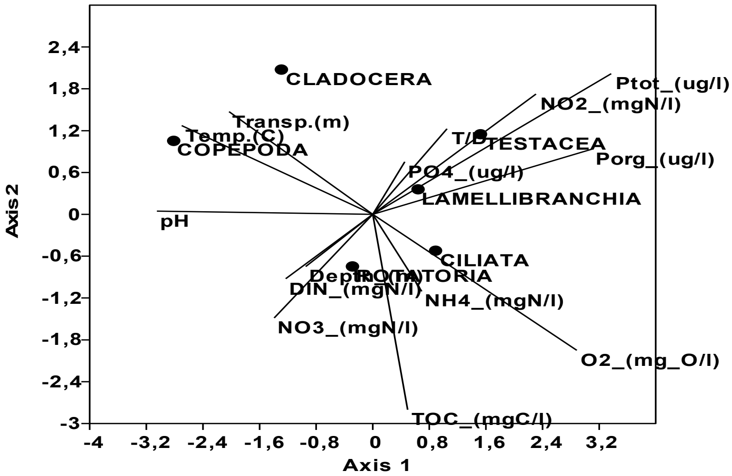

Fig. 7. The ordination (CCA) for zooplankton and environmental parameters.

Table 4
Permutation test for phytoplankton

Axis	Eigenvalue	%	p
1	0.086311	59.99	0.009901
2	0.038266	26.6	0.009901
3	0.0097924	6.806	0.08911
4	0.0069347	4.82	0.0495
5	0.0025789	1.792	0.2475

Table 5
Permutation test for zooplankton

Axis	Eigenvalue	%	p
1	0.05948	49.42	0.009901
2	0.026614	22.11	0.009901
3	0.014003	11.64	0.009901
4	0.0073228	6.084	0.009901
5	0.0050602	4.204	0.009901
6	0.0036324	3.018	0.009901

PHYTOPLANKTON

Spatial dynamics of phytoplankton species richness differs from one kind of ecosystem to another.

The Bacillariophyceae had the highest contribution to phytoplankton community, observed mainly in spring and autumn (81.33%, 74%, respectively). Indeed, the role of diatoms in lotic aquatic ecosystems is widely recognized (Bere & Tundisi, 2010).

Compared with other previous studies (1960-1961) (Brezeanu & Prunescu, 1962; Brezeanu *et al*., 1966), considerable changes in hydrochemistry and biotic parameters have been found in the present period.

The anthropogenic impact was visible mainly by the richness of phyto-plankton species (confirmed by Shannon diversity index): a decrease of species number was noticed in canals, while the natural sectors were favorable for the development of the phytoplankton community in the entire period. In canals, high speed of water flow and high degree of turbulence are obstacles in the development of plankton and submerged macrophytes.

High values of evenness show a good distribution of the number of individuals among phytoplankton species found in these areas. This response was possibly due to unfavorable conditions (high current velocity, increased turbulence, high load of suspended solids).

Using the Bray-Curtis similarity analysis the structural parameters of phytoplankton were tested on three years of study and distinct areas. The year 2008 evidenced a different pattern for phytoplankton species richness distribution. The resemblance between canals and meanders is confirmed by Bray Curtis cluster analysis, indicating a 94% similarity, the natural sectors distancing from them with 84% (Fig. 8). The results show that the years 2009 and 2010 are similar in high percentages in terms of species richness (94.14%) (Fig. 9).

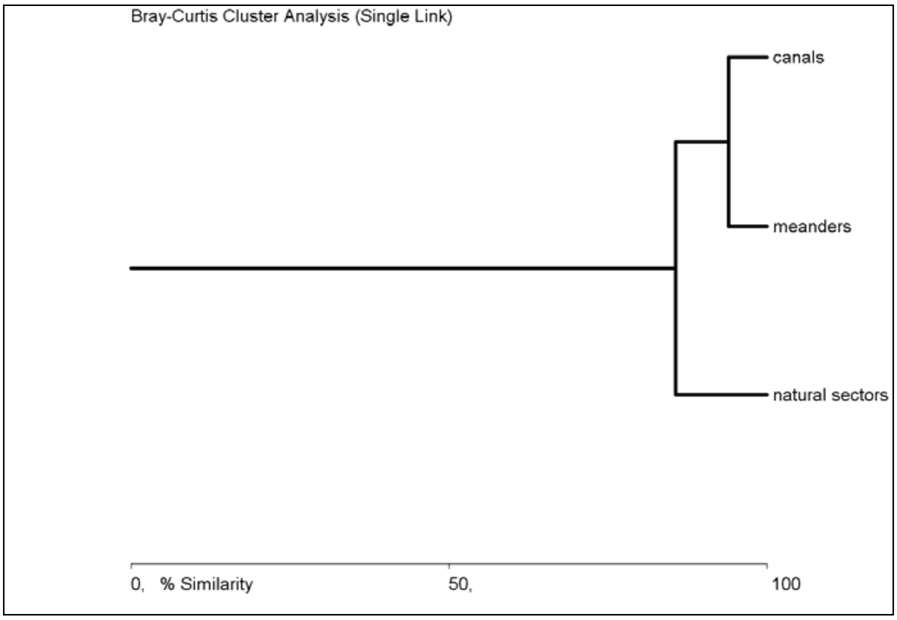

Fig. 8. The phytoplankton species richness similarity in areas studied.

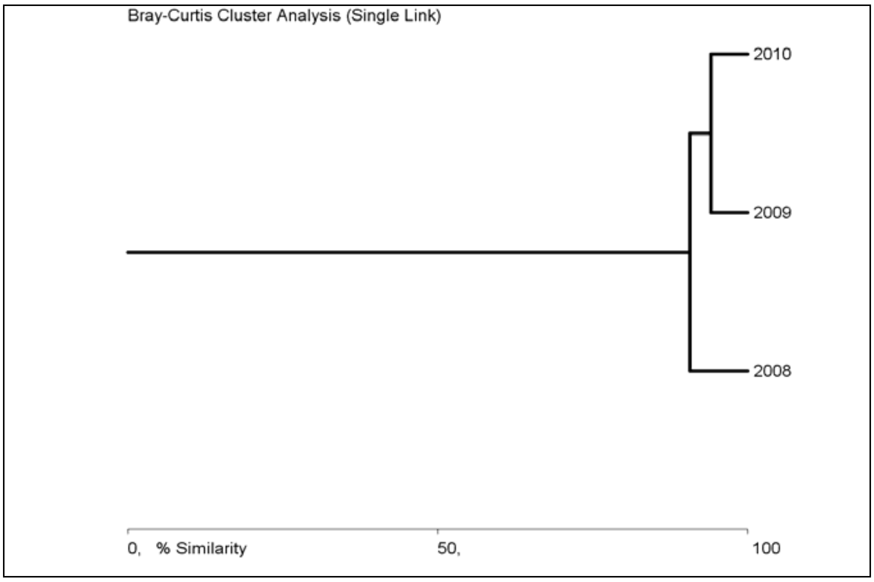

Fig. 9. The phytoplankton species richness similarity in the period studied.

Natural areas have the highest number of species in all seasons, while in canals and meanders the number of species is lower, with significant variations depending on the season. Shannon index calculated for each season confirms this pattern of distribution of diversity in the arm of Sfântu Gheorghe. Evenness did not show significant fluctuations, by years, seasons, or between sections studied.

In order to test phytoplankton community variables in Sfântu Gheorghe branch for statistically significant differences between the three years of study, a one-way ANOVA was applied. The test has shown statistically significant differences between the three years of study, for species richness ($p < 0.01$).

The diversity of phytoplankton community was influenced by the species richness ($r = 0.93$, $R^2 = 0.87$, $p < 0.05$), while the evenness explained only 31% of diversity variations ($r = 0.55$, $R^2 = 0.31\%$, $p < 0.05$). The Simpson dominance (D) showed a strong statistical inverse correlation with the Shannon index of phytoplankton ($R = -0.95$ after Pearson). This confirms that, in the period with low diversity, only few species dominated in terms of abundance and biomass (Botnariuc & Vădineanu, 1982). The dominance index decreased with the uniform distribution of individuals among species (Wilsey *et al.*, 2005).

ZOOPLANKTON

The pressure of natural and anthropogenic control factors on zooplankton community has left its mark on species richness (Fantin-Cruz *et al.*, 2011). In the

1981-1985 and 1991-1992 periods, 222 species were recorded, while between 2008-2010 their number decreased by 12% (Zinevici & Parpală, 2007). However, a comparison among species richness of zooplankton in different periods and areas of the Danube river, indicates superior values in Sfântu Gheorghe branch (176 species) to that of the Austrian river territory (over 30 species 1994) (Reckendorfer *et al.*, 1999).

After hydraulic works performing to rectify the looped course of Sfântu Gheorghe branch, in this area significant changes occurred on physical, hydrological and geological parameters (Popa, 1997). The separation of the meanders seems to be favorable to zooplankton diversity (Fig. 5).

It is known that Sfântu Gheorghe waters have low organic matter content (Postolache, 2006). However, the meanders record high TOC values (8.89 mg C/L) comparing with other areas (7.88 mg C/L in natural sectors and 6.43 mg C/L in canals). Perhaps, this is due to the reduction of water turbulence, of the flow velocity and of the washing degree of the sediment.

In these conditions submersed vegetation development is favored that is a refuge for zooplankton, such as some species of Ciliata (Foissner *et al.*, 1991, 1992, 1994); Testacea (Bartoš, 1954); Cladocera (Negrea, 1983); Copepoda (Damian-Georgescu, 1963, 1966, 1970; Dussart & Defaye, 2001) or Rotatoria (Rudescu, 1960; http://rotifer.acnatsci.org/rotifer.php).

Following the conditions of meanders, where the water residence time for zooplankton development (Basu & Pick, 1996) is closer to the lentic systems (Popa, 2007), are conducted to a higher specific richness of zooplankton, than in the lotic systems (Zinevici & Parpală, 2007). Thus for the entire period of study, here the highest species richness (128 species) was found.

The increased diversity of zooplankton in the meanders was confirmed by comparing the results with reference to our previous studies before the anthropogenic impact, that shows the Sulina, Tulcea and Sfântu Gheorghe branches have much lower taxonomic spectra (29-67 taxa) (Popescu, 1962; Brezeanu & Prunescu-Arion, 1962; Popescu-Marinescu *et al.*, 1990), even if the floodplain exerts a favorable influence on the flora and fauna of the Danube period (Baranyi *et al.*, 2002).

The low percent of constant species in the Sfântu Gheorghe branch (between 3.53% in natural sectors and 4.68% in meanders) defines an unbalanced system (Table 6).

This assumption is based on certain arguments. Thus, the values of ecological parameters compared with those of lentic ecosystems (Zinevici & Parpală, 2007) are the result of the cumulative effect of hydrotechnical works, global climate change, physical and chemical control factors. A slightly higher number of constant species of meanders is in favor of the conclusion that meanders suffer a slow process of ecological succession from a lotic ecosystem type to a lentic one.

The constant presence of cladocerans in meanders is an additional argument that the low water velocity in these areas is favorable to submerged macrophytes development. They become a suitable habitat for the phytophilous species (Negrea, 1983). This suitable habitat increased zooplankton diversity (Parpală *et al*., 2008).

Table 6

Constant species (C) in Sfântu Gheorghe branch (2008-2010).

Persistent species	**S**	**M**	**C**
TESTACEA			
Arcella arenaria Greef	C		C
LAMELLIBRANCHIA			
Dreissena polymorpha (Pallas)	C	C	C
ROTATORIA			
Asplanchna priodonta Gosse	C	C	
Brachionus angularis Gosse		C	
B. calyciflorus dorcas Gosse	C	C	
Keratella cochlearis Gosse			C
Synchaeta oblonga Ehrenberg			C
CLADOCERA			
Bosmina longirostris (O.F.Müller)		C	
Diaphanosoma orghidani Negrea		C	

S = Natural sectors; M = Meanders; C = Canals

The diversity index recorded a downward trend in areas where human impact was manifest, especially in canals, but also in meanders compared to natural sectors. This situation was also confirmed in the plankton seasonal and annual dynamics, by equal distribution of individuals within species, with evenness values 0.6 (Table 3).

Using the Bray-Curtis similarity analysis the structural parameters of zooplankton were tested on three years of study and distinct areas. It was registered a 93.22% similarity between natural sectors and meanders in zooplankton diversity reflecting the close hydromorphological conditions in these areas (Fig. 10). The results show that the years 2008 and 2010 are similar in high percentages in terms of specific richness (86.39%) (Fig. 11). The year 2009 evidenced a different pattern for zooplankton species richness distribution. The same results were confirmed by applying single factor ANOVA ($p < 0.01$).

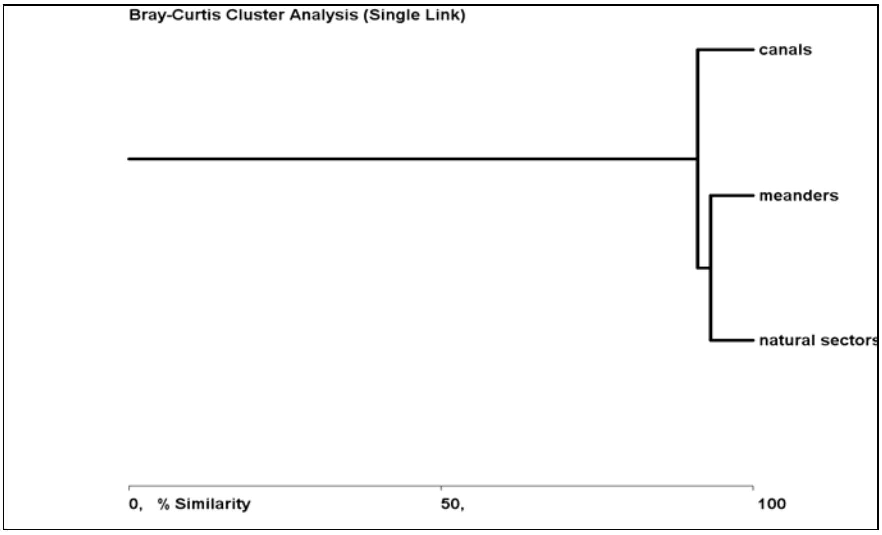

Fig. 10. Similarity cluster for zooplankton species richness in the areas studied.

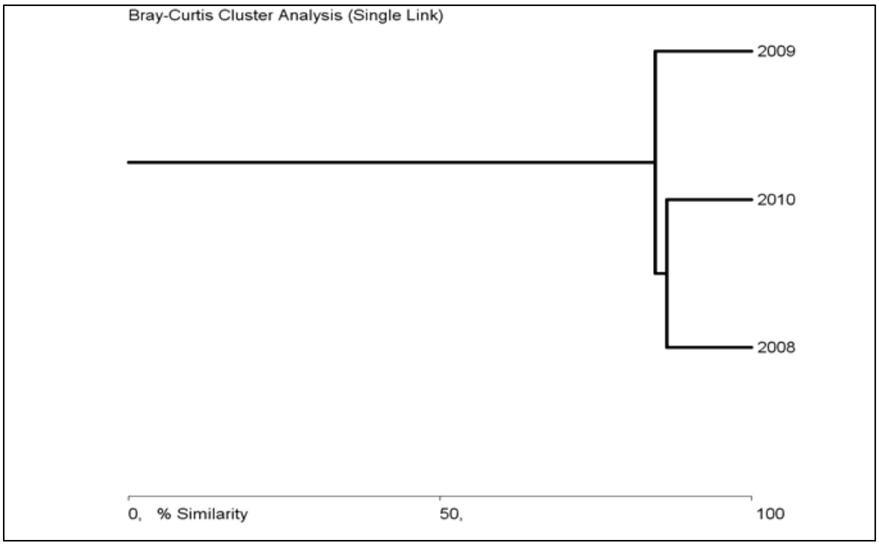

Fig. 11. Similarity cluster for zooplankton species richness in the period studied.

It was noticed a tendency towards changes in the hydrogeomorphological features of the meanders and newly built canals structure caused by anthropogenic impact of the hydrotechnical works in the Sfântu Gheorghe branch (Popa *et al.*, 1995; Popa, 1997). This effect is reflected also by the structure of the phyto- and zooplankton communities.

CONCLUSIONS

In the canals 102 phytoplankton species were recorded, compared to 136 found in the natural sectors. These results were strengthened by the Shannon diversity which ranged between 4.05 (spring 2009) in natural sectors and 1.99 (autumn 2009) in canals. Also, the maximum of zooplankton species richness was found in meanders, in 2008 (76 species), while the minimum, in canals in 2010 (49 species). The cutting off the meanders seems to be favorable to zooplankton diversity.

The related hydromorphological conditions between natural sectors (reference areas) and meanders were underlined also by the 93.22% similarity of the zooplankton diversity.

Under the anthropogenic impact, the sectioned meanders become less functional, in terms of water circulation, suffering a slow ecological succession to lentic ecosystem type, more advantageous than canals for aquatic flora and fauna development.

Most probably depending on the Sfântu Gheorghe branch hydrological regime these zones would become shallow lakes in the future.

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