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LONG-TERM DYNAMICS OF ZOOPLANKTON IN THE MATIȚA AND MERHEI SHALLOW LAKES (THE DANUBE DELTA, ROMANIA). 1. DIVERSITY AND ABUNDANCE

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Abstract. The present paper presents significant changes occurred in the multi-annual dynamics of zooplankton diversity and abundance (1980-2007), under the pressure of human-induced eutrophication in two shallow lakes specific for the Danube Delta. Zooplankton community from lakes Matița and Merhei was characterized by high species richness but low abundance values until 1981, in ecological conditions unaffected by eutrophication. For the next ten years, due to obvious increases of human pressures, zooplankton species richness decreased with 52% and 63%, respectively, while abundance values increased with 39% and 16%, respectively. After 1991, the social and economic changes in the Danube countries from the Central Europe led to nutrient input decreases. As a result, lake ecosystems from the Danube Delta showed lower trophicity values and their ecological parameters tended to recover. Analyses on the dynamics of the Shannon-Wiener's informational entropy index, Pielou's evenness and Simpson's index of dominance offered additional information and reduced the heterogeneity of the data regarding the species richness and the numerical abundance dynamics. Moreover, correlation analyses suggested the influences of human-induced changes of nutrient inputs on the multi-annual zooplankton dynamics.

Résumé. Des recherches à long terme, effectuées au cours de la période 1980-2007, sur le zooplancton de deux lacs de petite profondeur (Matița et Merhei) qui sont représentatifs pour le système lacustre du Delta du Danube, mettent en évidence des modifications significatives de quelques paramètres écologiques. Elles sont la conséquence de variations amples du niveau de trophie écosystémique, générées par le facteur anthropique. On met en évidence trois périodes distinctes du point de vue écologique: la période de méso-eutrophie (1980), la période d'eutrophie-hypertrophie (1981-1991) et la période caractérisée par une légère tendance de rétablissement de l'état de référence (1992-2007). Au cours de la première période le zooplancton des lacs Matița et Merhei est caractérisé par une richesse en espèces (119, respectivement 128 espèces), corrélée avec des valeurs relativement réduites de l'abondance (223, respectivement 387 ind./l). Au cours de la seconde période, la richesse en espèces se réduit drastiquement (avec 52%, respectivement 63%), de manière concomitante avec une croissance évidente (avec 39%, respectivement 16%) de l'abondance. Les recherches effectuées au cours de la troisième période mettent en évidence le fait que le processus de redressement de la diversité et de l'abondance du zooplancton est un processus lent et oscillant. La dynamique des indices d'entropie informationnels Shannon-Wiener, d'équitabilité Pielou et de dominance Simpson, corrélée avec la richesse en espèces et la dominance numérique indiquent une tendance d'abaissement de stabilité de la communauté zooplanctonique, due à l'accroissement du niveau de trophie, depuis la méso- vers la hypertrophie. La composition des espèces constantes en fréquence et de celles dominantes en nombre diffère d'une manière significative d'une période à l'autre, un nombre limité d'espèces maintenant ces caractéristiques au cours de toute la période analysée.

Key words: zooplankton, the Danube Delta, shallow lakes, diversity, abundance.

INTRODUCTION

The Matița-Merhei complex is one of the largest lake systems in the Danube Delta (Romania). It is located in the central region of the Letea Island, comprising 108 shallow lakes, stretching on a surface of 5700 ha. Lakes Matița (642 ha) and

Merhei (1368 ha) are the largest lakes from the complex (Gâștescu, 1971; Constantinescu & Menting, 2000). They are located at: 45^{0}19' N, 29^{0}37' E and 45^{0}17' N, 29^{0}22' E, respectively (Fig. 1).

The great distance from the lakes to the Danube River branches and the long-term siltation of the spillway rivulet in Merhei Lake led to the poor water circulation of the two lakes.

Characterized by a shallow depth (1.74 m), Merhei Lake perimeter has a high degree of sinuosity compared to Matița Lake, thus having a higher value of the ratio between the shore line length and the total surface, a significant detail in zooplankton diversity dynamics.

In ecological conditions unaffected by eutrophication, the low depth of Merhei Lake favors the development of rich submerged vegetation, unlike Matița Lake.

Fig. 1 - Matița and Merhei lakes from the Danube Delta Biosphere Reserve (after Grigoraș & Constantinescu, 1995, touristic map).

The long-term research carried out in lakes Matița and Merhei showed drastic changes in trophicity levels (Postolache, 2006; Vădineanu et al., 1989), together with the shift from the dominance of macrophyte primary producers to phytoplankton. In natural conditions, these changes occur over long periods of time, but here they were visible in only a few decades due to human impacts (Cărăuș & Nicolescu, 2006).

These changes of ecological factors have been reflected in the structure and functions of aquatic communities (Rîșnoveanu & Vădineanu, 2003), including zooplankton (Zinevici & Parpală, 1992). They have been observed in our analyses from three ecologically-different periods of time, as follows: first, the period of natural balance (before 1981), characterized by meso-eutrophic conditions; second, the impact period (1981-1991), characterized by eutrophic and hypertrophic conditions; and third, the partial recovery period of structural and functional characteristics (1992-2007), characterized by the return to eutrophic conditions (Zinevici & Parpală, 2006).

The long-term studies concerning lakes Matița and Merhei can offer an image of the biocenotic structure dynamics of the entire Danube Delta lacustrine systems. A similar zooplankton dynamics, influenced by the increased human-induced eutrophication has been described in the South-Western shallow lagoons of the Baltic Sea as well (Feike et al., 2007).

Our research focuses on the changes occurred in the monthly, annual and multi-annual dynamics of zooplankton species richness and abundance, for all three periods of trophic state evolution.

The correlations between zooplankton and phytoplankton ecological parameters, together with the nutrient dynamics can point out the outstanding role played by the trophic state in zooplankton community dynamics. Analysis on the main ecological parameters of zooplankton community dynamics, but also on the nutrients and the structure of planktonic primary producers showed their dependence on the trophic status of ecosystems.

The use of the Shannon-Wiener's informational entropy index, Pielou's evenness and Simpson's index of dominance are able to correct and fill in the gaps of heterogeneous analysis of species diversity dynamics.

Using the „kriging" technique, the study presents for the first time the maps of the dynamics of zooplankton diversity. The method confirms once again the evolution of zooplankton diversity in Matița and Merhei lakes.

There are numerous difficulties related to long-term studies, like the present analyses on zooplankton community from lakes Matița and Merhei, for instance. This is the reason why long term syntheses are less frequent compared to short- or medium-term studies. Literature data are used frequently to fulfil the gaps that are usually present in the long term series, but the results can still be inconclusive due to the use of different methods (Clark et al., 2001; Kane, 2009). When different methodological approaches are comparable, the authors of syntheses are able to capture the true dynamics sense, even without the benefit of high precision analyses (Pitois & Fox, 2006).

The data used in analyzing zooplankton dynamics from lakes Matița and Merhei from 1980 to 2007 are the results of a unitary set of field and laboratory methods, carried out by the authors.

MATERIALS AND METHODS

The research took place between 1980 and 2007. The sampling, carried out monthly during the vegetation period (March-October), took place in 5 sampling sites for each ecosystem, using a 5 l Patalas-Schindler derrick. For each sample, 50 l were collected from the whole water column.

The samples were concentrated by filtering through a gauze planktonic net with a mesh size of 65 μm and subsequently by siphonage. The samples were preserved in 4% formaldehyde and analyzed using a planktonic microscope.

The ecological parameters were studied for each species. Data were subsequently aggregated for the total zooplankton community taxonomic groups, but also for the following trophic levels: herbivores and predators.

Taxonomic analyses reflected species richness. For species identification the following keys were used: Foissner et al., 1991, 1992, 1994, 1995; Kahl, 1930; (Ciliata); Bartoš, 1954; Grospietsch, 1972 (Testacea); Rudescu, 1960; Kutikova, 1970; Ruttner-Kolisko, 1974 (Rotatoria); Negrea, 1983; Brooks, 1959 (Cladocera); Damian-Georgescu, 1963, 1966, 1970 (Copepoda).

In order to establish the zooplankton trophic structure the following titles were used: Karabin, 1985; Hillbricht-Ilkowska, 1977; Kryuchkova, 1989 etc.

Zooplankton density was expressed as number of individuals/l.

The species with a frequency index that varied between 50 and 100% were considered persistent species. The first two species from the relative numerical abundance point of view were selected as dominant species.

The statistical analyses were focused on three directions:

1. Analysis of biological diversity. Distributions of specific abundances were compared and three biodiversity indices were calculated in addition to analyzing the species richness: Shannon-Wiener's informational entropy index, Pielou's evenness, Simpson's index of dominance (Magurran, 1988).

In addition to the computation of these indices, two tests were used for comparisons between the years, periods, or ecosystems: distributions of specific abundances were compared using the χ^2 test (Petrișor, 2000), comparisons involving Shannon-Wiener's informational entropy index were made using the t (*Student*) test (Magurran, 1988; Batten, 1976).

The values of all indices and tests were computed considering the monthly, annual and multi-annual dynamics (1980-2007), for all three periods of trophic state evolution and for every combination year-month, using Microsoft Excel spreadsheets. P-values were determined using the GraphPad Software on-line p-value calculator available at http://www.graphpad.com/quickcalcs/ PValue1.cfm.

2. Analysis of correlations. Coefficients of determination were computed using Microsoft Excel Data Analysis extension between any of the following variables, when available: zooplankton density, species number and the value of Shannon-Wiener's informational entropy index.

All statistical calculations pertaining to the first two directions were performed, when possible, for several levels of data aggregation presented in table 1, for each ecosystem separately. Correlations were accounted for only if found significant ($p \leq 0.05$) any three of the eight levels of data aggregation in at least one of the two ecosystems. It is noteworthy mentioning that the reduced sample size (<30) could reduce the power of statistical analyses only on levels c, d, f, and g.

3. Spatial analyses of the densities of each taxonomic group, as well as for several ecological parameters: diversity measured by Shannon's Informational Entropy Index and species richness. The analyses were performed using ArcGIS 9.2 spatial interpolation through ordinary kriging over a virtual space defined by the

Table 1

Levels of data aggregation used in statistical analyses.

Primary level	Secondary level	Explanation	Number of observations	Notation	Remarks
I. Raw data	Raw data	Data grouped in separate rows for any possible combination of the year of collection, month of collection, species, taxonomic group, and trophic level	15372 (Matița), 13818 (Merhei)	a	
II. Data summed by year	Year and taxonomic group	Data aggregated by both year (summing data by year regardless of the month) and taxonomic group (summing data for all species within the group)	120 (Matița), 100 (Merhei)	b	Additional analyses for herbivores and predators separately
	Year and trophic level	Data aggregated by both year and trophic level (summing data for all taxonomic groups and species within the same level)	24 (Matița), 20 (Merhei)	c	
	Total	Data aggregated by year (summing data for all trophic levels, taxonomic groups, species, and months)	12 (Matița), 10 (Merhei)	d	
III. Data summed by period	Period and taxonomic group	Data aggregated by both period (summing data for all years within the period) and taxonomic group (summing data for all species within the group)	30 for both lakes	e	Additional analyses for herbivores and predators separately
	Period and trophic level	Data aggregated by period and trophic level	6 for both lakes	f	
	Total	Data aggregated by period (summing data for all trophic levels, taxonomic groups and species, and also for all years within the period)	3 for both lakes	g	
IV. Data summed by year and month	Year, month, and trophic level	Data aggregated by year and month (summing data for all trophic levels, taxonomic groups and species)	63 (Matița), 48 (Merhei)	h	

year and month (Cheval & Petrişor, 2003). The results were represented by prediction maps that highlighted clusters of either low values or high values, providing a visual overview of the overall status of analyzed parameters, but not a statistical measure of variation.

The data on DIN/TRP ($\mu g/l^{-1}$), phytoplankton density and biomass dynamics included in the correlation analyses were taken from the literature (Drăgășanu et al., 1960; Vădineanu et al., 1989; Rîșnoveanu & Vădineanu, 2000; Oosterberg & Bogdan, 2000; Oltean & Nicolescu, 1985; Cărăuș & Nicolescu, 2006).

RESULTS

From over almost three decades (1980-2007) of analysis, the zooplankton community of lakes Matița and Merhei showed high species richness (272 species and 283 species, respectively). The ecological structure of zooplankton included a mixture of typical planktonic species, vegetation and nektonic-benthic species.

The taxonomic structure of herbivores reflected a clear dominance of rotifers in both ecosystems (56.52-57.92%). As for the predators, cyclopoid copepods were dominant (59.38-73.33%) (Fig. 2).

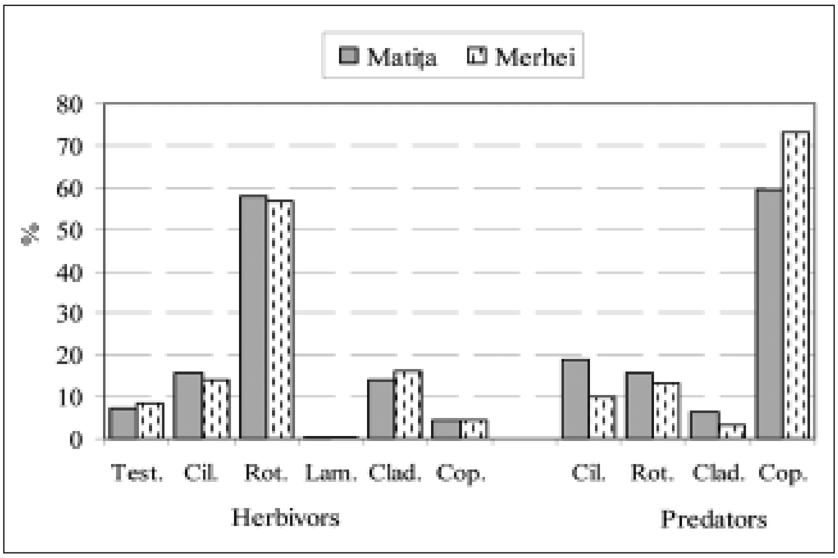


Fig. 2 - The taxonomic structure and species richness of zooplankton in Matița and Merhei lakes from 1980 to 2007.

The multi-annual averages of zooplankton density in the two lakes were 859 and 1022 ind./l, respectively. Ciliates represented the most abundant community in the two lakes (34.28-29.48%), followed by rotifers (26.46-35.29%) as herbivores and cyclopoids as secondary predators (52.13% and 79.54%, respectively) (Fig. 3).

There were significant differences concerning the dynamics of annual values of species richness and numerical abundance between 1980 and 2007: an obvious decline in the first case related to the significant growth in the second case. The highest values of species richness (128 species in Matița Lake, 119 in Merhei Lake) (Fig. 4) and the lowest densities (387 and 232 ind./l, respectively) (Fig. 5) were recorded in 1980, the reference year for the meso-eutrophic conditions. These differences were caused to a great extent by human-induced changes of nutrient concentrations, but also by natural variations of hydrological and thermal regimes.

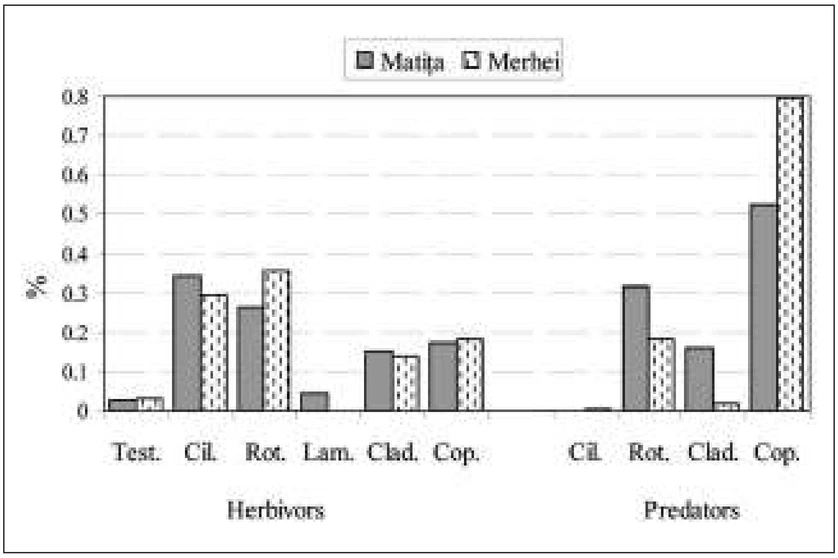


Fig. 3 - The multi-annual average values of zooplankton numerical abundance in Matița and Merhei lakes (average values from 1980 to 2007).

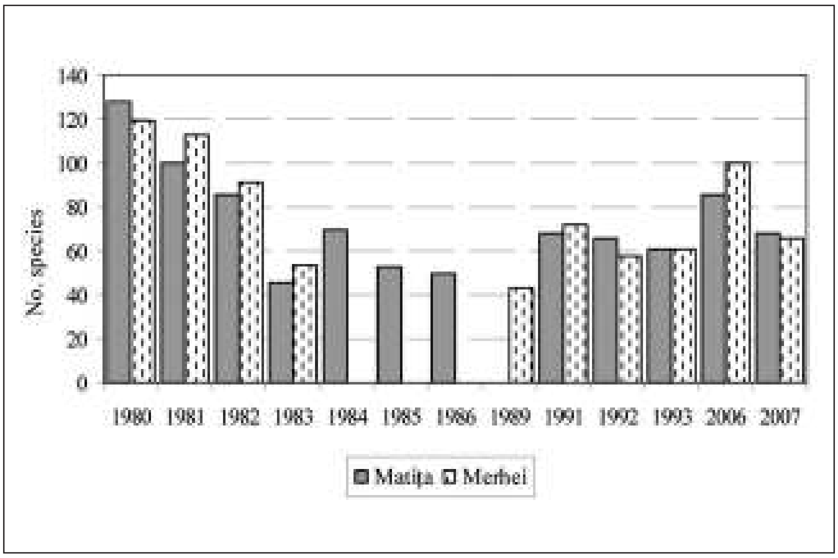


Fig. 4 - Dynamics of annual values of zooplankton species richness in Matița and Merhei lakes (1980-2007).

The rise of trophic state to hypertrophic values during 1981-1991 led to obvious decreases in species richness (with 47.66% in Matița Lake and 36.98% in Merhei Lake). On the other hand, the zooplankton density increased 2.6 and 6.2 times, respectively (Tabs 2, 3).

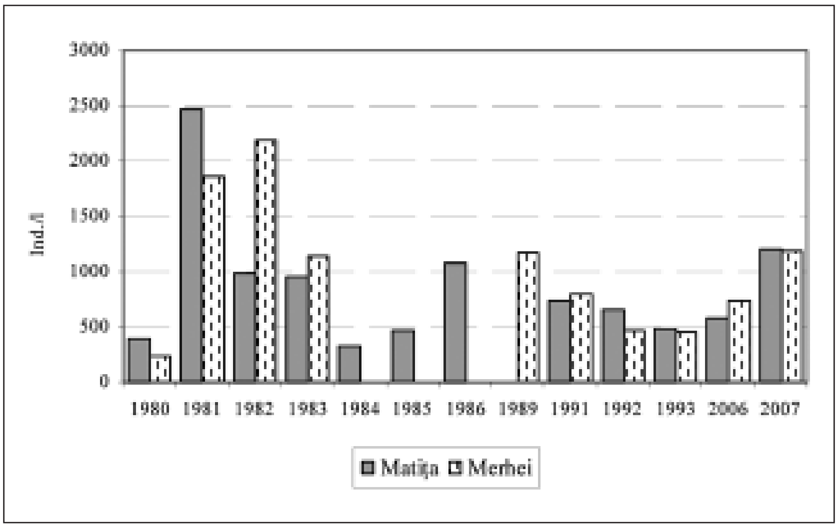


Fig. 5 - Dynamics of annual values of zooplankton numerical abundance in Matița and Merhei lakes (1980-2007).

After 1991, zooplankton community tended to return to the initial values of ecological parameters, while the trophic levels slightly decreased.

Persistent and dominant species played important roles in the dynamics of zooplankton community structure and functions. Persistent species represented only 9.19% and 9.54 % respectively, from the species composition in lakes Matița and Merhei between 1980 and 2007, while dominant ones represented 2.57% and 3.53% respectively from all the species identified in the study period (Tabs 4, 5).

Shannon-Wiener's informational entropy index dynamics indicated a downward trend in the relationship between species richness and their degree of abundance. Values recorded in 1980, in meso-eutrophic conditions, were the highest in the study period. In 1983, the index recorded the lowest values from the period 1980-2007, due to hypertrophic conditions. In 2006, because of a lower eutrophication impact, the informational index increased, while in 2007 it decreased again (Fig. 6 a).

Pielou's evenness index dynamics showed decreasing trends of uniformity in the distribution of individuals per species. As with the Shannon-Wiener informational index, peaks were observed in 1980, and minima in 1983 and early structural restoration in 2006 (Fig. 6 b).

The Simpson's index of dominance recorded a more pronounced downward dynamics. The highest values were recorded in 1980 and the lowest in 2007 (Fig. 6 c).

Table 6 includes the correlation results between zooplankton parameters and figure 7 shows a selection of spatial analysis results concerning the evolution trend of zooplankton diversity between 1980 and 2007. All these aspects are the results of statistical analyses corresponding to the directions stated in table 1.

Table 2

Average values of zooplankton species richness from Matița and Merhei lakes in three periods: reference (1980), impacted by eutrophication (1981-1991) and ecological recovery (1992-2007).

Taxonomic structure	No. of species and %	1980	1981-1991	1992-2007
Matița Lake				
Herbivores	No. of species	112	58	63
Testacea	%	13.39	13.37	15.04
Ciliata	%	2.68	5.73	7.52
Rotatoria	%	59.83	58.6	60.15
Lamellibranchia	%	0.89	0.64	0.75
Cladocera	%	18.75	15.29	13.53
Copepoda	%	4.46	6.37	3.01
Predators	No. of species	16	9	7
Ciliata	%	18.75	11.54	-
Rotatoria	%	25.00	19.23	30.00
Cladocera	%	6.25	7.69	10.00
Copepoda	%	50.00	61.54	60.00
Total	No. of species	128	67	70
Merhei Lake				
Herbivores	No. of species	109	66	64
Testacea	%	11.93	14.81	11.27
Ciliata	%	2.75	9.26	7.04
Rotatoria	%	52.29	54.32	64.8
Lamellibranchia	%	0.92	0.62	0.7
Cladocera	%	27.52	14.81	14.08
Copepoda	%	4.59	5.49	2.11
Predators	No. of species	10	9	7
Ciliata	%	10.00	4.76	12.50
Rotatoria	%	10.00	9.52	25.00
Cladocera	%	-	4.76	6.25
Copepoda	%	80.00	80.96	56.25
Total	No. of species	119	75	71

Table 3

Average values of zooplankton numerical abundance from Matița and Merhei lakes in the following periods: reference (1980), impact caused by eutrophication (1981-1991) and ecological recovery (1992-2007).

Taxonomic structure	Ind./l and %	1980	1981-1991	1992-2007
Matița Lake				
Herbivores	ind./l	357.5	974.3	683
Testacea	%	0.92	0.56	7.32
Ciliata	%	16.85	44	12.33
Rotatoria	%	58.39	19.22	38.48
Lamellibranchia	%	4.58	2.42	8.18

Table 3 (continued)

Taxonomic structure	Ind./l and %	1980	1981-1991	1992-2007
Cladocera	%	5.66	17.84	10.19
Copepoda	%	13.2	15.21	23.5
Predators	Ind./l	29.2	25.8	46.8
Ciliata	%	-	-	0.21
Rotatoria	%	73.21	27.91	29.06
Cladocera	%	1.23	8.53	25.64
Copepoda	%	25.74	63.56	45.09
Total	Ind./l	386.7	1000.1	729.8
Merhei Lake				
Herbivores	Ind./l	225.3	1370.6	677
Testacea	%	2.66	3.61	1.59
Ciliata	%	2.66	39.55	6.23
Rotatoria	%	43.1	21.06	70.64
Lamellibranchia	%	0.18	0.09	0.46
Cladocera	%	4.26	18.8	2.84
Copepoda	%	47.14	16.89	18.24
Predators	Ind./l	6.7	57.8	34
Ciliata	%	-	-	1.76
Rotatoria	%	26.87	14.19	26.47
Cladocera	%	-	2.08	0.88
Copepoda	%	73.13	83.73	70.89
Total	Ind./l	232	1428.4	711

Table 4

The main persistent species from 1980 to 2007 and the dynamics of their frequency index (%) in periods with different trophic levels.

Persistent species	Ecosystem	1980	1981-1991	1992-2007	1980-2007
Herbivores					
Brachionus angularis Gosse	Matița	66.67	72.29	80.00	72.99
	Merhei	55.55	89.97	75.00	73.51
Filinia longiseta (Ehrenberg)	Merhei	77.78	73.68	50.00	67.16
Keratella cochlearis (Gosse)	Merhei	66.67	81.58	55.00	67.75
Polyarthra remata (Skorikov)	Matița	77.78	51.85	55.00	61.54
Bosmina longirostris (O. F. Müller)	Matița	88.89	72.22	50.00	70.37
	Merhei	88.89	78.95	35.00	67.61
Chydorus sphaericus (O. F. Müller)	Matița	55.55	77.78	75.00	69.44
	Merhei	88.89	86.84	80.00	85.24

Table 5

The dominant species from a numerical point of view in periods with different trophic levels.

Persistent species	Ecosystem	1980	1981-1991	1992-2007	1980-2007
H e r b i v o r e s					
Carchesium polypinum (Linnaeus)	Matița	+	+	-	-
Epystilis plicatilis Ehrenberg	Merhei	-	+	-	-
Keratella cochlearis (Gosse)	Matița	-	-	+	-
	Merhei	-	-	+	-
Keratella quadrata (O.F. Müller)	Merhei	+	-	-	-
Synchaeta oblonga Ehrenberg	Matița	+	-	-	-
Synchaeta pectinata Ehrenberg	Matița	-	-	+	-
	Merhei	-	-	+	-
Chydorus sphaericus (O.F. Müller)	Matița	-	+	-	-
	Merhei	-	+	-	-
P r e d a t o r s					
Didinium nasutum (O.F. Müller)	Merhei	+	-	-	-
Asplanchna brightwelli (Gosse)	Merhei	+	-	-	-
Asplanchna herricki de Guerne	Matița	-	-	+	-
Asplanchna priodonta Gosse	Matița	+	+	+	+
	Merhei	-	+	+	-
Acanthocyclops vernalis vernalis (Fischer)	Matița	-	+	-	-
	Merhei	-	+	-	-
Mesocyclops crassus (Fischer)	Merhei	-	-	+	-
Leptodora kindtii (Focke)	Matița	+	-	-	-

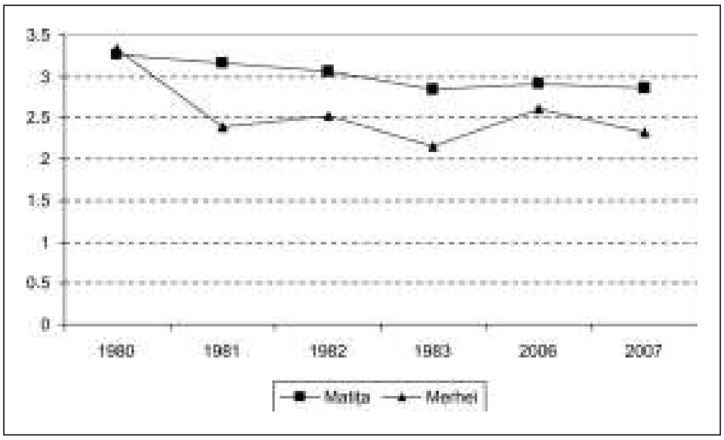
DISCUSSIONS

The trophic state of lakes Matița and Merhei before 1981 (included in the incipient mesotrophic-eutrophic limits) was characterized for the primary producers by the clear dominance of submerged macrophytes compared to planktonic producers (Enăceanu, 1953). Water blooms were rare during this period; they were short and located only in the upper layers of the water column. As a result, the biomass of primary producers recorded in most cases values that did not exceed the threshold of water blooms (5 mg wet weight/l) (Oltean, 1985).

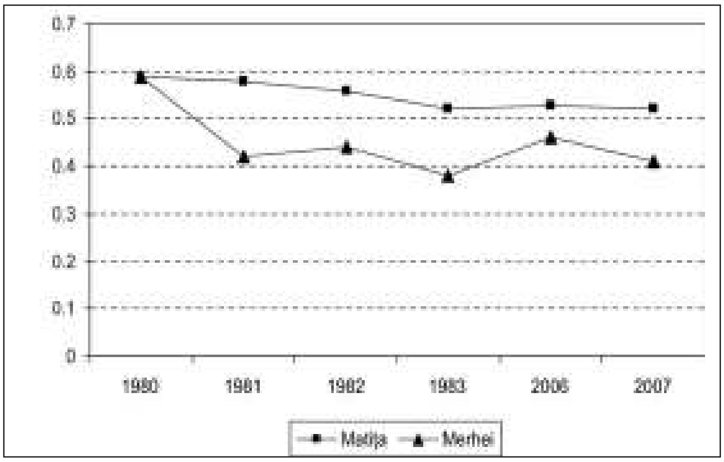
Small chlorophyceae (nano-planktonic; Ø: 5-25 µm), well represented in the phytoplankton community, were an important food source for macro-consumer zooplankton. Aggregates composed of detritus and bacteria (Ø: 1-5 µm), coming from the decomposition of submerged macrophytes (especially at the end of vegetation season) and unconsumed algae also represented a significant food source, mainly for micro-consumer zooplankton.

The environment heterogeneity was positively influenced by the high abundance and diversity of submerged macrophytes, specific to Merhei Lake and to a certain extent to Matița Lake.

a. Shannon-Wiener's informational entropy index



b. Pielou's evenness



c. Simpson's index of dominance

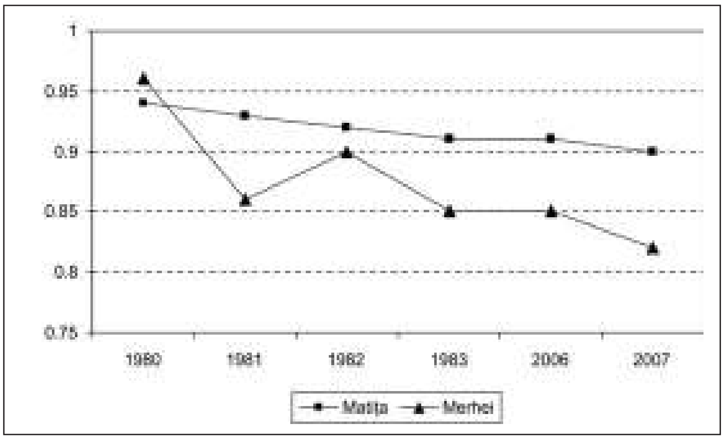


Fig. 6 - Dynamics of annual values of zooplankton diversity and dominance indicators in Matița and Merhei lakes (1980-2007).

Table 6

Significant correlations ($p \leq 0.05$) between zooplankton parameters in lakes Matița and Merhei.

Correlated variables	Level of data aggregation (please see *Table 1*)															
	a		b		c		d		e		f		g		h	
	R	p	R	p	R	p	R	p	R	p	R	p	R	p	R	p
Matița Lake																
Zooplankton density and the number of species	0.08	*	0.34	*	0.68	*	0.15	0.65	0.63	*	0.57	0.24	-0.92	0.26	0.08	0.53
Shannon-Wiener's informational entropy index and the number of species	N/A	N/A	N/A	N/A	0.92	*	0.67	**0.05**	N/A	N/A	0.85	**0.03**	0.98	0.10	0.53	*
Merhei Lake																
Zooplankton density and the number of species	-0.21	*	0.50	*	0.69	*	0.12	0.74	0.82	*	0.48	0.33	-0.76	0.45	-0.21	0.16
Shannon-Wiener's informational entropy index and the number of species	N/A	N/A	N/A	N/A	0.87	*	0.73	0.06	N/A	N/A	0.97	*	0.85	0.36	0.47	*

N/A - not analyzed; * - significant at the 0.001 level; values in bold - significant at the 0.05 level; gray shading indicates statistical significance at a level less than the 0.05 threshold

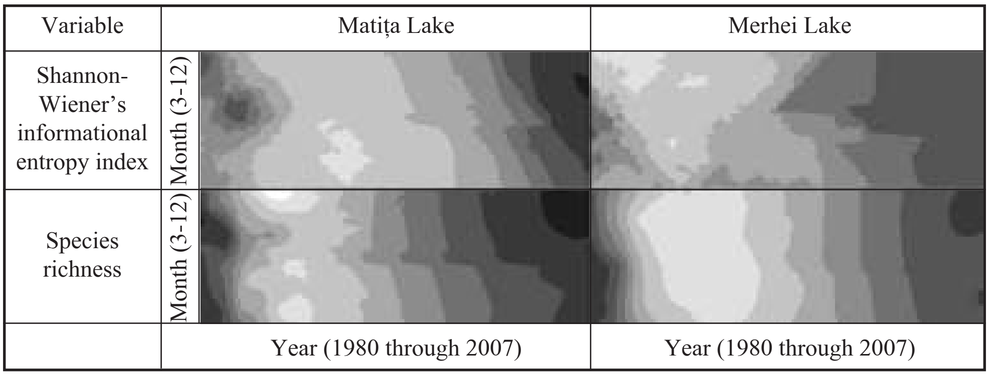


Fig. 7 - Ordinary kriging maps of zooplankton diversity evolution measured using Shannon-Wiener's informational entropy index and the species richness in lakes Matița and Merhei. The gray shades indicate increases from low values (white) to high values (black) for both Shannon-Wiener's index and the species richness.

The presence of various food sources together with the high heterogeneity of the environment favored the formation of zooplankton communities characterized by high species richness in both lakes, but especially in Merhei Lake. The higher values of species richness in the second lake were caused by higher abundances of submerged vegetation and higher values of the ratio between the shore line length and the total surface.

The limitation of food sources for zooplankton community, characteristic to low-trophicity ecosystems before 1981, led to low values of numerical density.

Density data showed that eutrophication impact was more severe in Merhei Lake due to its deficient hydrological regime. This was caused by advanced siltation of Sulimanca spillway rivulet, the only possibility of water removal from Merhei Lake. On the contrary, Matița Lake had numerous ways of water outlet.

Beginning with 1981, significant increases in ecosystem trophic levels occurred, ranging between meso – to hypertrophic values. They were caused by human impacts and were aggravated by the hydrological and thermal regimes (Vădineanu et al., 2000; Rîșnoveanu, Postolache & Vădineanu, 2004; Postolache, 2006). Before 1981, DIN/TRP recorded high values, with a maximum of 96.6. Between 1981 and 1991 the values decreased, reaching a minimum of 8.5 in 1988. Beginning with 1997, a slightly growth trend was noticed, DIN/TRP reached 20.3 (Fig. 8).

Under hypertrophic conditions, water blooms became frequent and affected the whole water column. Annual averages of primary producer density increased more than three times in both lakes. Biomass also increased 11 times in Merhei Lake and 9 times in Matița Lake (Fig. 9) (Oltean & Nicolescu, 1985; Cărăuș & Nicolescu, 2006). The obvious increases of primary producer biomass were caused not only by the increasing number of individuals, but also by the ratio between micro-planktonic and nano-planktonic species. Long-term zooplankton dynamics of species richness and numerical abundance had a similar variation (Zinevici & Parpală, 2000).

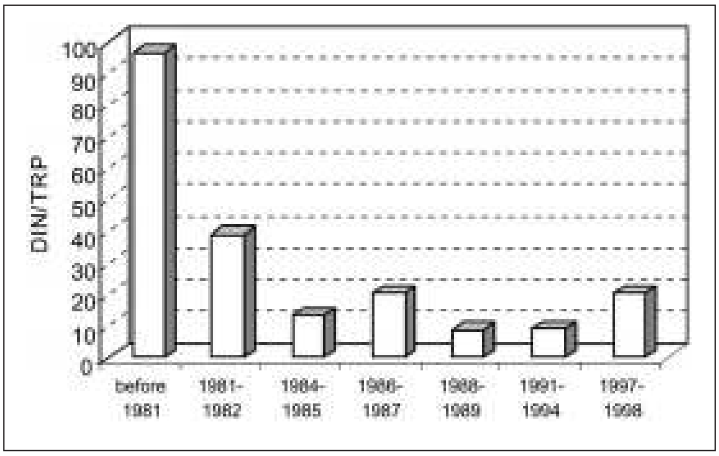


Fig. 8 - The dynamics of the water column DIN/TRP ($\mu g/l^{-1}$) ratio in the lower Danube River and the Danube Delta.

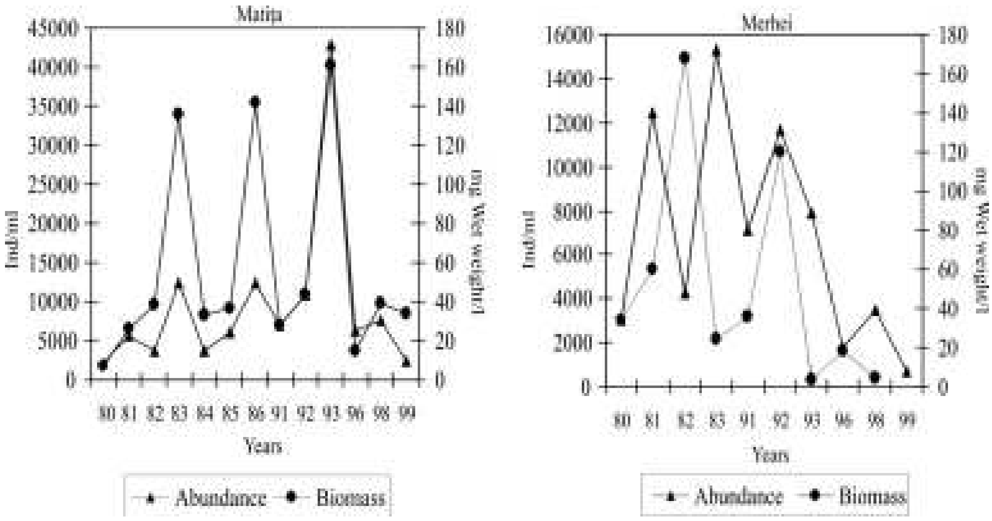


Fig. 9 - Phytoplankton density and biomass dynamics in lakes Matița and Merhei (Cărăuș & Nicolescu, 2006).

Planktonic primary producers caused the disappearance of submerged macrophytes by means of faster nutrient recycling and water transparency decreases. As a final effect, the heterogeneity of lake system decreased (Vădineanu et al., 2000).

This drawback in environment heterogeneity, together with the changes occurred in planktonic primary producers caused drastic decreases of zooplankton species richness during the poly- and hypertrophic phases. However, zooplankton abundance increased significantly.

The correlation between the two parameters showed the unfavorable character of the ecological changes for an important part of zooplankton species, according to the Thienemann principle (Botnariuc & Vădineanu, 1982). However, these changes of primary producers were favorable for cyanobacteria, capable to develop in the new ecological conditions, leading to significant increases of the total zooplankton density values: 2469.95 ind/l in Matița Lake and 2180.6 ind/l in Merhei Lake (Fig. 5).

A slight recovery tendency of diversity and structure of aquatic communities in the Danube Delta lake ecosystems occurred beginning with 1992, due to social and economic changes in some countries located in the Danube catchment area. These changes also affected the zooplankton community from lakes Matița and Merhei. However, zooplankton recovery process was slow and variable and it might have been significantly influenced by global climate change recorded in the region after the year 2000 (Zinevici & Parpală, 2007).

The dynamics of the Shannon-Wiener's informational entropy index, the Pielou's evenness and the Simpson's dominance index, correlated to species richness and numerical abundance dynamics showed the decreasing trend of zooplankton community stability, due to increases of the ecosystem trophic level from mesotrophic to hypertrophic.

Analyses of the before-mentioned parameters revealed that the restoration of ecological stability due to lower human-induced eutrophication impact was an extremely slow and oscillating process.

Comparative analyses of zooplankton in both lakes showed a more acute worsening of the ecological conditions, due to deficient hydrologic regime.

Changes in trophic levels between 1980 and 2007 significantly altered the structure and dynamics of persistent and dominant species that played an important role as key species in the structure and function of zooplankton community, viewed as a whole.

In the framework of drastic changes occurred in the dynamics of ecological factors, only a small number of persistent or dominant species became representative for the entire research period (Tabs 4, 5). Such situation has also been found in other ecosystem types (Ikauniece, 2001).

The species with the highest values of the persistence index, calculated for the period 1980-2007 were: *Brachionus angularis* Gosse, *Polyarthra remata* (Skorikov), *Bosmina longirostris* (O. F. Müller) and *Chydorus sphaericus* (O. F. Müller), in Matița Lake; *Brachionus angularis* Gosse, *Filinia longiseta* (Ehrenberg), *Keratella cochlearis* (Gosse), *Bosmina longirostris* (O. F. Müller) and *Chydorus sphaericus* (O. F. Müller), in Merhei Lake (Tab. 4).

Most of the numerical dominant species were characteristic only for one out of three study periods characterized by different trophic states. *Keratella quadrata* (O. F. Müller), *Synchaeta oblonga* Ehrenberg, *Didinium nasutum* (O. F. Müller), *Asplanchna brightwelli* (Gosse) and *Leptodora kindtii* (Focke) were characteristic for the mesotrophic-eutrophic period. *Epystilis plicatilis* Ehrenberg, *Chydorus sphaericus* (O. F. Müller) and *Acanthocyclops vernalis vernalis* (Fischer) were characteristic for the hypertrophic period and *Keratella cochlearis* (Gosse), *Synchaeta pectinata* Ehrenberg, *Asplanchna herricki* de Guerne and *Mesocyclops crassus* (Fischer) were specific for the period of recovery from hypertrophic to eutrophic conditions. *Carchesium polypinum* (Linnaeus) was the dominant species in the first two periods and *Asplanchna priodonta* Gosse was dominant in the last two periods (Merhei Lake) or in all three periods (Matița Lake) (Tab. 5).

The correlations between species richness and zooplankton density were significant, like those between species richness and the Shannon-Wiener's informational entropy index (Tab. 6).

The dominance of micro-consumer zooplankton, compared to macro-consumer zooplankton generated insignificant correlations between phytoplankton and zooplankton community.

Conclusions

The long-term research that extended on three decades in the shallow lakes Matița and Merhei showed important changes in species richness, species identity and abundance dynamics of plankton consumers. These changes were mainly caused by large variations of trophic levels between meso- to hypertrophic values, correlated with changes of the submerged macrophytes/phytoplankton ratio and changes in environment heterogeneity.

The dynamics of these parameters mentioned above showed several different phases from an ecological point of view: the natural balance period (1980), the human impact period (1981-1991) and the recovery period (1992-2007). Analyses carried out in the initial period showed high values of zooplankton diversity (119-

128 species), correlated to relatively low values of numerical abundance (232-387 ind./l). In the second period, a drastic diversity drawback was recorded (67-71 species), together with obvious increases of abundance (1000-1428 ind./l). In the third period, a slight tendency of recovery was observed because the two parameters recorded values comparable to those from the initial period (70-71 species, 711-730 ind./l respectively). However, the recovery process was slow and variable. It seemed to be strongly influenced by changes in hydrological and thermal regimes that became more and more acute after 2000.

The component of persistent and dominant species varied significantly during the three different periods of ecological research.

Long-term dynamics of specific richness, numerical abundance, as well evenness, diversity and dominance indices reflected the trend of progressive worsening of environmental conditions of zooplankton in Matița Lake and especially in Merhei Lake. This situation was caused by eutrophication and poor hydrological regime.

The changes of zooplankton dynamics from lakes Matița and Merhei from 1980 to 2007 could be considered representative for the whole lacustrine system in the Danube Delta. Provided to decision factors from the Danube Delta Biosphere Reserve, these long-term research data would contribute to an improved biodiversity management of this protected area.

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DINAMICA PE TERMEN LUNG A ZOOPLANCTONULUI DIN LACURILE DE MICĂ ADÂNCIME MATIȚA ȘI MERHEI (DELTA DUNĂRII, ROMÂNIA). 1. DIVERSITATE ȘI ABUNDENȚĂ

REZUMAT

Cercetări pe termen lung, efectuate în perioada 1980-2007, asupra zooplanctonului din două lacuri de mică adâncime, (Matița și Merhei) reprezentative pentru sistemul lacustru din Delta Dunării, evidențiază modificări semnificative ale unor parametri ecologici. Ele sunt consecința unor variații ample ale nivelului de trofie ecosistemică, generată de factorul antropic.

Se evidențiază trei perioade distincte din punct de vedere ecologic: perioada de meso-eutrofie (1980), perioada de eutrofie-hipertrofie (1981-1991) și perioada caracterizată printr-o ușoară tendință de revenire la starea de referință (1992-2007).

În prima perioadă zooplanctonul lacurilor Matița și Merhei se caracterizează prin bogăție specifică ridicată (119, respectiv 128 specii), corelată cu valori relativ reduse ale abundenței (223, respectiv 387 ind/l). În cea de a doua perioadă, bogăția specifică se reduce drastic (cu 52%, respectiv 63%), concomitent cu creșteri evidente (cu 39%, respectiv 16%) ale abundenței. Cercetările efectuate în cea de a treia perioadă evidențiază faptul că procesul de refacere a diversității și abundenței zooplanctonului este un proces lent și oscilant.

Dinamica indicilor de entropie informațională Shannon-Wiener, de echitabilitate Pielou și de dominanță Simpson, corelată cu bogăția specifică și dominanța numerică indică tendința de scădere a stabilității comunității zooplanctonice datorată creșterii nivelului de trofie de la meso la hipertrofie.

Componența speciilor constante ca frecvență și a celor dominante numeric diferă semnificativ de la o perioadaă la alta, doar un număr limitat de specii menținându-și aceste caracteristici în decursul întregii perioade analizate.

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