THE ZOOPLANKTON OF LAKE SNAGOV (ROMANIA): DIVERSITY, STRUCTURE AND PRODUCTION

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Lake Snagov is the largest natural ecosystem of lacustrian type in the Romanian Plain. It was formed by natural crossing of the confluence area of river Ialomiţa and a small tributary river. From a climate perspective, the area belongs to temperate continental Central European zone. Lake Snagov emphasized early mesotrophy-eutrophy status. The optimal concentration of nutrients, the high environmental heterogeneity, the existence of aquatic macrophytes and an adequate trophic base, represented the favoring factors of high specific richness correlated with balanced values of abundance, biomass and daily production of zooplankton.

Key words: river shore, meso-eutrophy, species richness, abundance, biomass, daily production.

INTRODUCTION

The Lake Snagov is the largest natural lake of the Romanian Plain. The geographical position of the lake is 44°43'34" north latitude and 26°10'40" east longitude. This lake has a stream origin. It was formed by the barrage of the river confluence area with a small tributary. The process was facilitated by the existence of extremely low slopes of river Ialomiţa in that sector, as well as the huge amount of silt carried in the periods of maximum annual hydrological cycles (Gâştescu, 1963; Morariu *et al*., 1968). This process of clogging was possible in the conditions of a more humid climate than today, produced and maintained by secular forests that dominated the Romanian Plain area. The county name in the Romanian Plain (Teleorman), derived from the Turkish "Deli Orman" (Mad Forest), suggests the climatic conditions of the area during the formation of the lake. The further movement of the river in order to avoid the clogged sector removed the lake from its power supply and also the excess of water drain. With some flashing these links were still maintained through small streams usually created in the maximum hydrological periods.

The lake water belongs to bicarbonate type, characterized by a low degree of mineralization (Morariu *et al*., 1968).The main source of water comes from Ialomiţa – Colentina Channel, located in a relatively remote area, in the extreme upstream basin of the former tributary of the River Ialomiţa. The stream of water passes through a swampland heavily clogged and cross small lakes, reaching the Lakes Tâncăbeşti 1 and 2 that continue to Lake Snagov. A complementary source is the springs on the lake bottom, banks and rainfalls.

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The water drainage is done through a small channel located in the extreme shore, which replaces the old clogged backwater Gruiu. The construction of a small dam at the mouth of the channel allows the maintenance of a constant level of water in the lake and protects riparian localities against flooding.

The riparian area on the right side of the lake situated between profiles 1 and 4 is arranged for residential purposes. They arranged lawns, hangars were built to protect boats and, in some areas, the reed were cleared and the banks were concreted. Instead, the left side is almost entirely occupied by secular woods. Also, in the left side of the lake, between profiles 4 and 5, there is a populated island, with significant historical past.

Until now, the ecological research aimed at vegetation associations, birds and mammals. Few studies on zooplankton ecology were performed. There is one bibliography source targeting cladocerans, which represents only one of the six systematic groups of zooplankton. The research was conducted by Ştefan Negrea in 1952. Noted, however, the data have been published only three decades later in the volume of Fauna of Romania, Cladocera group.

MATERIAL AND METHODS

The study was conducted in 2011 in April, May, July, September and October. Five sampling points were established in 2011 from five transversal sections (profiles), each having a coastal and medial point (Fig. 1). Exception occurred in April, when sampling was performed only in the littoral zone. The setting of sampling points took into account the high hydro-geomorphological heterogeneity of the ecosystem.

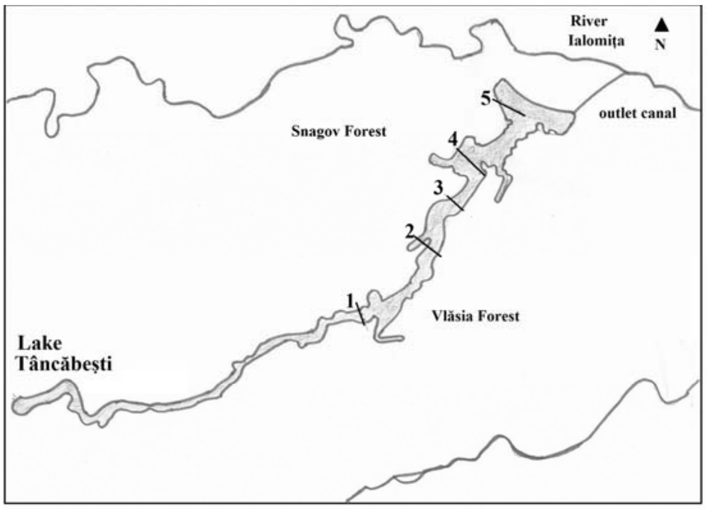

Fig. 1. The map of Snagov Lake with sampling profiles (modified after http://www.fundatiasnagov.ro/).

The samples were taken on water column with a Patalas Schindler plankton trap (5 L). 30 L were filtered through plankton net mesh with 65µm Ø and preserved in 4% formaldehyde.

Species identification was made using a Zeiss inverted microscope, according to specific keys.

The abundance (ind L^{-1}) was assessed by microscopic methods, by direct counting into a Kolkwitz chamber (Utermöhl, 1958).

The biomass (µg wet weight L^{-1}) was calculated using data from the literature on species, sex, stage and size classes (Nauwerck, 1963; Osmera, 1966; Odermatt, 1970; Dumont *et al*., 1975; Hillbricht-Ilkowska, 1977). The production (µg wet weight L^{-1}/24h) was evaluated according to: Winberg (1971); Edmondson & Winberg (1971); Edmondson (1974); Andronikova (1976); Pederson & Welch (1976) and Hillbricht-Ilkowska (1977).

STATISTICAL DATA

We calculated the Shannon-Wiener diversity index (H) and Evenness (E). Correlations between zooplankton parameters and some environmental parameters (DIN/TRP ratio, depth, transparency and water temperature) were calculated.

These processings were made using XLSTAT statistical software.

RESULTS

The Lake Snagov is an elongated, narrow and meandering ecosystem suggesting the image of the former tributary and its flood area. It has a length of 16.5 km, the width gradually increasing from 200 m upstream to 600 m (in the extreme downstream). The average depth is 5 m and the maximum reached 11.5 m. In the medial 1-4 profiles, depth varies between 7 and 11.5 m. In contrast, the upstream end (profile 5) shows an obvious clogging and the water depth decreases at 2-2.5 m. The water depth of the 5 profiles (littoral zone) measured about 2 m.

In the ecological conditions of 2011 the zooplankton of Lake Snagov was characterized by high species richness, totaling 111 species. Of these, 100 are primary consumers and 11 species, secondary consumers. The dominant group in terms of diversity in the first trophic level was the rotifers, which amounted 55% and for the secundary consumers, the ciclopid copepods (45.45%) (Table 1).

The temporal dynamics revealed the highest values of specific richness of primary and secondary consumers in July and the lowest in the other two seasons (Fig. 2). Shannon diversity indicated the highest diversity in October due to good distribution of individuals among species, and the lowest in May (Fig. 3).

Table 1

The species richness of zooplankton in the vegetation period of the annual cycle (months IV-X) on trophic levels and systematic groups

Zooplankton group	C_1	C_2	$C_1 + C_2$
Testacea	10		10
Ciliata	10	4	14
Lamellibranchia	1		1
Rotifera	55	1	56
Cladocera	21	1	22
Copepoda	3	5	8
Total zooplankton	100	11	111

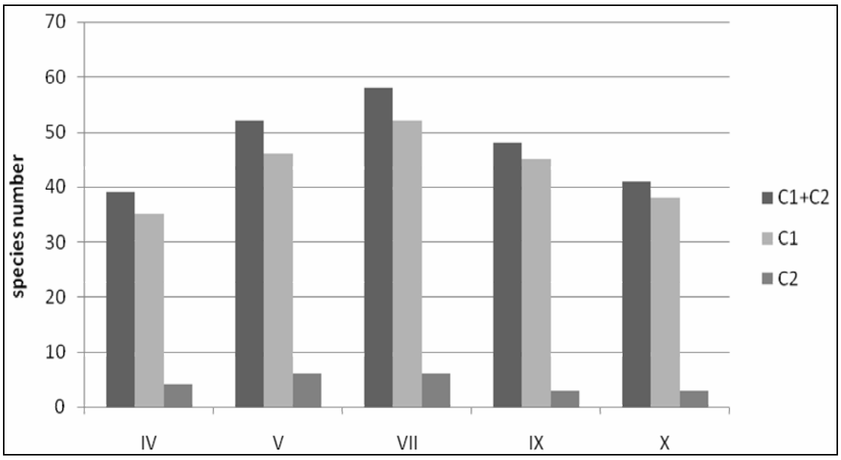

Fig. 2. The temporal dynamics of zooplankton species richness on trophic levels.

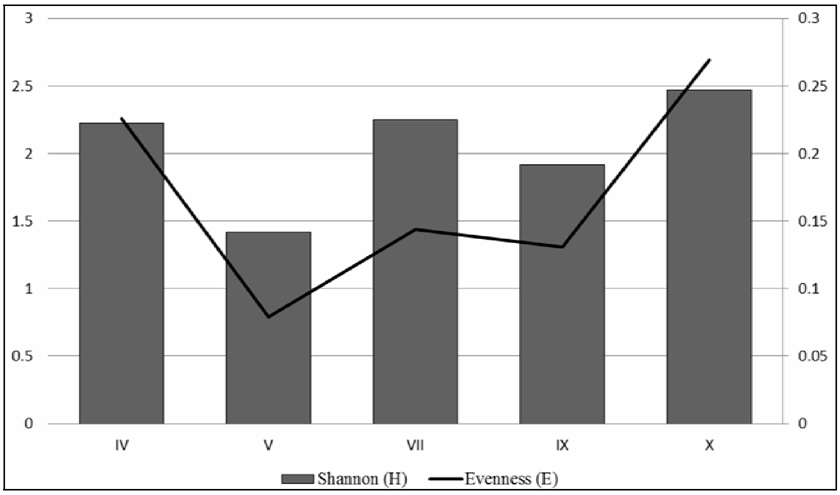

Fig. 3. The temporal dynamics of Shannon diversity and Evenness of total zooplankton.

Rotifera had the higher contribution in autumn and the lowest in May. Cladocera recorded the maximum in July, while the minimum was in spring. Copepods reached maximum values in May and minimum in October (Table 2).

Table 2

The temporal dynamics of species richness on systematic groups (%)

Zooplankton group	IV	V	VII	IX	X
Testacea	7.69	5.77	8.62	15.69	7.32
Ciliata	15.39	11.54	1.72		4.88
Lamellibranchia		1.92			
Rotifera	53.85	42.31	55.17	50.98	63.41
Cladocera	15.38	26.02	27.59	23.53	19.51
Copepoda	7.69	11.54	6.9	9.8	4.83
Total zooplankton	100	100	100	100	100

Over 82% of zooplankton species in Lake Snagov were accidental and 9% accessories. Only 3.6% species were euconstant and 5.4% constant (Table 3). Six decades ago, the cladocerans registered a total of 23 species (Negrea, 1983). A very close value (22 species) was reported in 2011, but 11 species of the initial list cannot be found in the current structure. Instead, their absence was compensated by the appearance of new species, maintaining the initial amplitude of the systematic group. It is premature to consider their absence as definitive, given that zooplankton showed important structural and functional variations from one year to another.

Table 3

The frequency of euconstant and constant species

Species	Euconstant (%)	Constant (%)
Asplanchna priodonta		66.67
Bosmina longirostris	84.44	
Brachionus diversicornis		55.55
Daphnia cucullata khalbergensis		73.33
Keratella cochlearis		64.44
Mesocyclops crassus	93.33	
Polyarthra dolychoptera	93.33	
Polyarthra major		57.78
Polyarthra remata	97.98	
Pompholyx complanata		53.33

The highest frequency is recorded by the rotifer *Polyarthra remata* (Skorokov, 1896). The euconstant rotifers were represented by two species, copepods and cladocerans only by one species (Table 3).

The average density registered a relatively high value (1394 ind L^{-1}). An analysis of the contribution of the two trophic levels highlighted an obvious difference between the value of primary consumer density (1342 ind L^{-1}) and the secondary consumers (49 ind L^{-1}). The high value of total zooplankton was due to the ciliates (671.7 ind L^{-1}) (Table 4). High zooplankton density evidenced in May (5092 ind L^{-1}). In September, the second peak was observed (Fig. 4).

Table 4
The average of zooplankton abundance in the vegetation period of the annual cycle (months IV-X) on trophic levels and systematic groups (ind L^{-1})

Zooplankton group	C_1	C_2	$C_1 + C_2$
Testacea	5.7		5.7
Ciliata	670.6	1.1	671.7
Rotifera	212.8	22.9	235.7
Cladocera	178	0.4	178.4
Copepoda	275.1	24.9	300
Total zooplankton	1342.2	49.3	1394.5

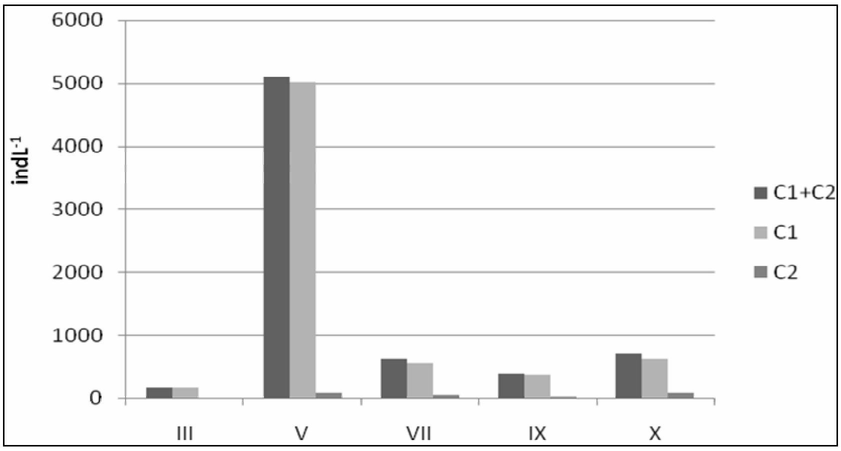

Fig. 4. The temporal dynamics of abundance on trophic levels.

Extremely high value in May was due to ciliates (almost 66%). However, their numeric contribution in the other months is zero or almost negligent. The rotifers had a major contribution to the total zooplankton in the other months, accompanied by copepods (with a peak in the second part of the vegetation season) (Table 5), similar to other studies (Sampaio *et al.*, 2002).

Table 5
The temporal dynamics of zooplankton abundance on systematic groups (%)

Zooplankton group	IV	V	VII	IX	X
Testacea	0.85	0.2	1.07	1.16	0.75
Ciliata	1.52	65.86			0.4
Rotifera	69.92	8.82	31.49	23	47.52
Cladocera	1.64	15.26	3.72	4.05	10.53
Copepoda	26.07	9.86	63.72	71.79	40.8
$C_1 + C_2$	100	100	100	100	100

The copepod *Mesocyclops crassus* (Fischer, 1853) revealed a particular situation: its nauplius larvae and copepodits ranked the species in the first position of primary consumers and the adult stages in the top of secondary consumers. Also, the ciliate *Carchaesium polypinum* (Linnaeus, 1758) and the rotifer *Asplanchna priodonta* (Gosse, 1850) were found dominant species (Table 6).

Table 6

The temporal dynamics of dominant species in terms of zooplankton abundance (%)

Trophic level	**C_1**		**C_2**	
Month	A	B	C	D
IV	5.11		3.85	88.46
V	4.67	59.77	32.8	51.15
VII	53.49		83.51	3.13
IX	63.32		81.25	7.41
XI	43.1		19.32	68.99
Xa	33.94	11.95	43.95	43.84

A. *Mesocyclops crassus* – nauplia and copepodits; B. *Daphnia cucullata khalbergensis*; C. *Mesocyclops crassus* – adult stage; D. *Asplanchna priodonta.*

The average of total zooplankton biomass revealed a high level (7934 µg wet weight L^{-1}). The C_1/C_2 ratio (12.5) illustrated the dominance of the first trophic level. The biomass structure of primary consumers and total zooplankton depended on cladoceran and copepods. In the case of secondary consumers, the first two positions are held by ciclopids and rotifers (Table 7).

Table 7

The average biomass of zooplankton in the vegetation period of the annual cycle (months IV-X) on trophic levels and systematic groups (µg wet weight L^{-1})

Zooplankton group	**C_1**	**C_2**	**$C_1 + C_2$**
Testacea	2.58		2.58
Ciliata	40.59	2.8	43.39
Rotifera	175.75	249.7	425.45
Cladocera	5328.71	44	5372.71
Copepoda	188.35	289.61	2089.09
Total zooplankton	7347.98	586.11	7934.11

The monthly maximum of total zooplankton biomass, situated at very high rates (28 435 µg wet weight L^{-1}) occurred in May. The secondary value recorded at the end of the season was lower (5412 µg wet weight L^{-1}) (Fig. 5).

The analysis of temporal dynamics of zooplankton biomass showed two maxima of testate amoebas, ciliates and rotifers in the extremities of vegetation season. This situation is specific to freshwater ecosystems (Bunnell *et al*., 2012). In the case of cladocerans the main peak appeared later in May, but the secondary peak in October. In the case of copepods, the first occurred in July-September and the second in April (Table 8).

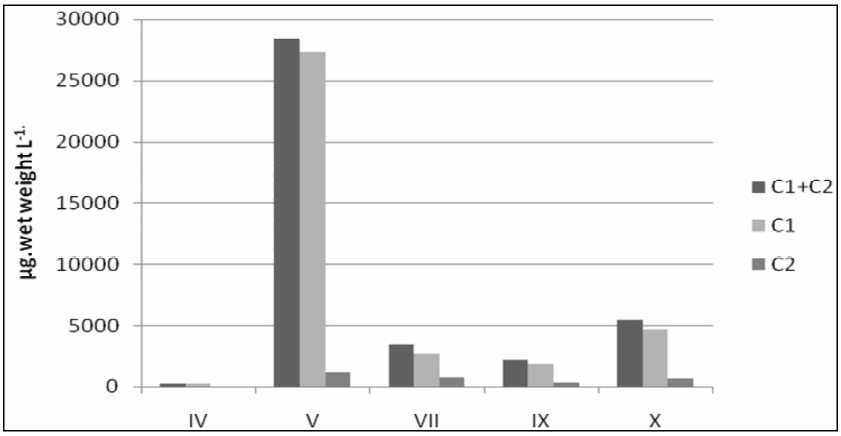

Fig. 5. The temporal dynamics of biomass on trophic levels.

Table 8

The temporal dynamics of zooplankton biomass on systematic groups (%)

Zooplankton group	**IV**	**V**	**VII**	**IX**	**X**
Testacea	0.68	0.01	0.08	0.09	0.04
Ciliata	1.29	0.75			0.02
Rotifera	23.13	3.92	8.77	3.53	10.74
Cladocera	15.57	76.83	22.56	33.66	64.31
Copepoda	59.39	18.49	68.59	62.72	24.89
$C_1 + C_2$	100	100	100	100	100

The copepod *Mesocyclops crassus* was dominant both in biomass level C_1 (due to nauplia and copepodit stages) and in C_2 (due to adult individuals). *Daphnia cucullata* (Sars, 1862) (Cladocera) and *Asplanchna priodonta* (Gosse, 1850) (Rotifera) were graded on the second places. The Mesocyclops juveniles and adults of *Daphnia cucullata* amounted 53.69% of the first trophic level and the Mesocyclops and *Asplanchna priodonta*, 70.15% of the secondary consumers (Table 9).

Table 9

The temporal dynamics of dominant species in terms of zooplankton biomass (%)

Trophic level	**C_1**		**C_2**	
Month	A	B	C	D
IV	17.96		0.76	26.95
V	3.28	14.13	21.17	58.79
VII	62.84	21.1	76.28	1.92
IX	60.03	22.51	74.46	4.94
XI	18.87	63.78	27.28	58.59
Xa	29.39	24.3	39.9	30.25

A. *Mesocyclops crassus* – nauplia and copepodits; B. *Daphnia cucullata khalbergensis*; C. *Mesocyclops crassus* – adult stage; D. *Asplanchna priodonta.*

The average value of daily production of 2011 (728 µg wet weight L^{-1}/24h) represented about 11% of biomass. The dominant group as production in the first trophic level belongs to cladocerans, while the second to the copepods (Table 10).

Table 10
The average of zooplankton production in the vegetation period of the annual cycle (months IV-X) on trophic levels and systematic groups (µg. s um. L^{-1}/24 h)

Zooplankton group	**C_1**	**C_2**	**$C_1 + C_2$**
Rotifera	61.14	31.88	93.02
Cladocera	452.11	8.32	460.43
Copepoda	34.94	139.74	174.69
Total zooplankton	548.19	179.94	728.14

The maximum value of production was reached in May. After a progressive decline registered in July and September, a new increase was recorded in October, indicating that it is much smaller than the value recorded in May (Fig. 6).

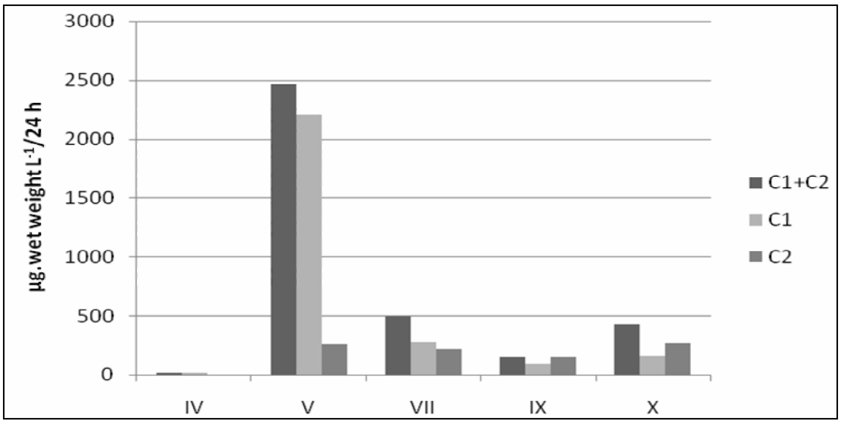

Fig. 6. The temporal dynamics of zooplankton daily production on trophic levels.

In the case of Rotifera, the highest percentage in zooplankton production was recorded in July, but an increasing occurred even at the beginning of the vegetation period. In the case of cladocerans and copepods the highest weight was recorded in October and April (Table 11).

Table 11
The temporal dynamics of zooplankton daily production on systematic groups (%)

Zooplankton group	**IV**	**V**	**VII**	**IX**	**X**
Rotifera	35.23	7.55	41.15	9.31	12.81
Cladocera	11.85	81.37	16.2	30.31	87.19
Copepoda	52.92	11.08	42.65	60.38	
$C_1 + C_2$	100	100	100	100	100

The species with the highest contribution to the production of zooplankton were *Daphnia cucullata* and *Bosmina longirostris* (O.F. Müller, 1785) (primary consumers), *Mesocyclops crassus* and *Asplanchna priodonta* (C_2). The first two species contributed 52.32 % in the first level and the last two 93.74% of the production of the second trophic level (Table 12).

Table 12

The temporal dynamics of the dominant species of zooplankton daily productivity on trophic level (%)

Trophic level	**C_1**		**C_2**	
Month	A	B	C	D
IV		4.8	52.86	33.57
V	12.27	49.26	39.6	44.54
VII	8.87	7.06	95.93	3.03
IX	45.46	41.67	97.15	1.98
XI	78.39	8.82	87.19	12.81
Xa	29	23.32	74.55	19.19

A. *Daphnia cucullata*; B. *Bosmina longirostris*; C. *Mesocyclops crassus*; D. *Asplanchna priodonta.*

DISCUSSION

The high ratio of DIN/TRP (Fig. 7) indicated the limiting role of phosphorus in the water of Lake Snagov, which conferred the meso-eutrophic status of the ecosystem (Barnett & Beisner, 2007). Phosphorus is a nutrient with a major role in the development and production of phytoplankton. It constitutes the main source of food for zooplankton (Botnariuc & Vădineanu, 1982; Vădineanu & Cristofor, 1985, 1987). This nutrient source can be used both directly and indirectly, as detrito-bacterial aggregates (Hillbricht-Ilkowska, 1977; Pourriot & Champ, 1982; Wetzel, 2001).

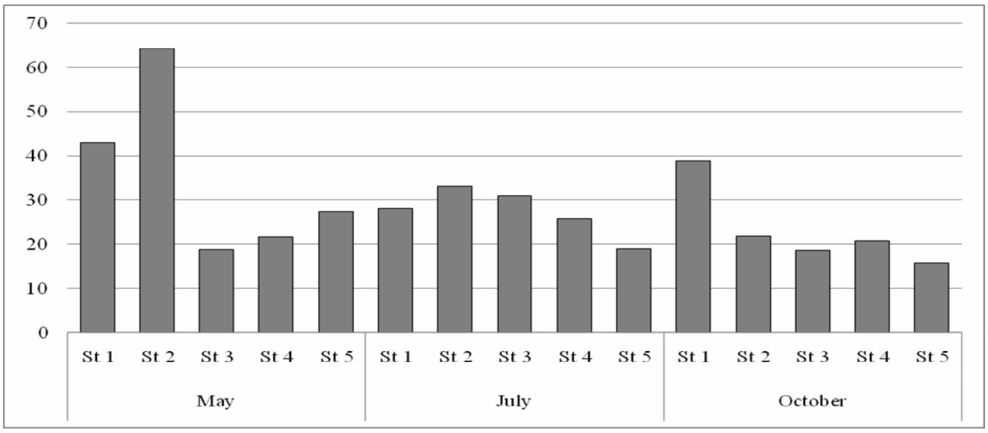

Fig. 7. The variation of DIN/TRP ratio in Lake Snagov.

In the conditions of reduced phytoplankton development and predominance of macrophytes-type primary producers (a situation highlighted in Lake Snagov), zooplankton food can be represented by detrito – bacterial aggregates.

The existence of various food sources created the premises of high specific diversity of zooplankton community, but other factors can contribute, such as high heterogeneity of the environment (Ferrara *et al*., 2002). This is a consequence of the existence of numerous microhabitats in the lake Snagov: free water with different depths, submerged and floating vegetation zones, golf and fairway areas.

High water transparency and the absence of industrial and agricultural pollutants represented other factors favoring diversity. The fluctuations of biotic parameters are not consequences of a single factor action. A combination of factors acted synergistically due to the multiple interactions in the ecological systems. This problem is solved in establishing a mathematical model to describe changes of the dependent variable based on changes in various factors as independent variables.

The regression statistics of the model showed that 49% of zooplankton abundance was explained by the tested variables (depth, transparency, temperature, DIN/TRP ratio). The Anova test of regression confirmed the validity of the model ($F_{4, 49} = 10.967$, p=2.71E-06). The depth and temperature had a significant influence on zooplankton abundance ($p<0.05$) (Table 13).

Table 13

The multiple regression of zooplankton abundance and some physical-chemical factors

Parameter	Coefficients	Standard Error	t Stat	p-value
Intercept	1.706	1.354	1.259	0.214
Ln(n+1)Depth	1.139	0.508	2.242	0.029
Ln(n+1)Temperature	1.376	0.557	2.469	0.017
Ln(n+1)Transparency	-0.256	0.349	-0.732	0.467
Ln(n+1)DIN/TRP	-0.056	0.363	-0.154	0.877

The evolution of urbanism and tourism in the area may affect the ecological characteristics of aquatic communities given that they will not take the appropriate measures for environment conservation. In the studied period high concentration of nitrogen in the water was registered. To mention is the low value of total phosphorus concentration, but the existence of elevated DIN/TRP ratio reduced the negative effects of this nutrient at the ecosystem level. Moreover, this chemical parameter influenced to a very small extent the dynamics of zooplankton abundance ($p>0.05$) (Table 13).

The accumulation of nitrogen in the water coming from the decomposition of high masses of vegetation dominated the invasive species *Nelumbo nucifera*.

Late development of aquatic vegetation, the main consumer of nutrients, determined in May 2011 an explosive proliferation of microbial biota, a suitable food source of ciliates. These, in turn, contributed to increased abundance, biomass and production of other zooplankton communities. Following these trophic connections, the maximum annual zooplankton, clearly exceeded the values of the other months, contributing to the development of relatively high zooplankton quantitative parameters.

CONCLUSIONS

The zooplankton of Lake Snagov is characterized by high specific richness (111 species) and balanced values of abundance (1400 ind L^{-1}), biomass (7900 µg wet weight L^{-1}) and production (730 µg wet weight L^{-1}/24h), corresponding to mesotrophic-early eutrophic ecosystem-type.

Among the favoring factors of zooplankton communities, the existence of optimal nutrient concentrations in the water, reflected in high levels of DIN/TRP ratio, ensures the role of phosphorus as limiting factor of eutrophication and determines the dominance of aquatic macrophytes despite phytoplankton.

The absence of pollutants, high environmental heterogeneity and the existence of an adequate trophic base also contribute to the favorable development of the zooplankton (68%) and the daily production (63%).

The community analysis reveals the dominance of rotifers in terms of species richness (50%) of ciliates as abundance (48%) and cladocerans, both as biomass (68%) and daily production (63%).

The analysis at the species level highlights the special contribution of euconstant species *Polyarthra remata*, *P. dolychoptera*, *Mesocyclops crassus* and *Bosmina longirostris* to the ecological equilibrium of zooplankton communities. The contribution of the species *Mesocyclops crassus*, *Carchaesium polypinum* and *Asplanchna priodonta* as dominance is important. The analysis of biomass reflects the importance of *Mesocyclops crassus*, *Daphnia cucullata* and *Asplanchna priodonta*, also as daily production.

The most significant species for the structure and production is *Mesocyclops crassus*, in terms of diversity, abundance, biomass and daily production.

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