THE ROLE OF PLANKTON COMMUNITIES IN THE FUNCTIONAL CAPACITY OF THE DANUBE DELTA ECOSYSTEMS – A LONG TERM STUDY

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Abstract. The paper aims to emphasize the long-term changes in the structure and ecological processes of planktonic communities in shallow lakes of the Danube Delta Biosphere Reserve as well as the consequences on the flows of goods and services these lakes offer to socio-economic systems. Under the eutrophication pressure, profound changes in biodiversity and energy flow were observed as compared to the reference period. The balance between submerged macrophytes and phytoplankton characterized the natural status of the Danube Delta lakes (1975 – 1980). This was changed by the eutrophication process with consequences on the entire food web structure. Phyto and zooplankton species richness decreased with 50%, with effects on the quality and quantity of production, as well as on the nutrient recycling rate. In Roșu Lake (a representative shallow lake used as case study), the phytoplankton and zooplankton biomass increased 50 and 8 times, respectively, due to increased nutrient supply and changes of micro/macro filter feeders ratio. A low level of increasing (1.7 times) has been recorded for the bacterioplankton biomass. The maximum impact of eutrophication (hypertrophic period) is characterized by the energy input via phytoplankton exclusively. Nutrient recycling rates by phytoplankton and zooplankton decreased 11 and 1.1 times, respectively as a result of structure and trophic relationship changes. Shift in the submerged macrophytes/phytoplankton ratio affected the composition of organic substrate with consequences on the bacterioplankton communities. Since 1991, due to economic changes in the Danube basin, a trend of trophic state recovery of lakes has been registered, first observed at the level of phytoplankton communities. The responses at the level of phytoplankton communities consisted in increased nutrient recycling rates (without reaching the maximum capacity from the reference period). Till 2001, zooplankton kept the decreasing trend started in 1975, whereas bacterioplankton registered significant values of nutrient-recycling that indicate the prevalence of degradation processes in the detriment of accumulation in self-biomass.

Keywords: energetic supply**,** nutrient storage, Danube Delta, eutrophication, ecosystem services.

Rezumat. Rolul comunităților planctonice în asigurarea capacității funcționale a ecosistemelor din Delta Dunării - studiu de lungă durată. Lucrarea îsi propune să scoată în evidență schimbările pe termen lung în structura și procesele ecologice ale comunităților planctonice din lacuri de mică adâncime din Delta Dunării, ca și consecințele acestora asupra fluxului de servicii furnizate de lacuri sistemelor socio-economice. Sub presiunea eutrofizării, au fost observate schimbări profunde în biodiversitate și fluxul de energie, comparativ cu perioada de referință. Statusul natural al lacurilor din Delta Dunării (1975 – 1980) era caracterizat de un echilibru între macrofitele submerse și fitoplancton. Acesta a fost schimbat cu consecințe asupra întregii structuri a rețelei trofice. Bogăția specifică a fito și zooplanctonului a scăzut cu 50%, cu efecte asupra calității și cantității producției, ca și a ratei de ciclare a nutrienților. În lacul Roșu (lac reprezentativ de mică adâncime), biomasa fito și zooplanctonului a crescut de 50, respectiv 8 ori, din cauza rezervei crescute de nutrienți și a schimbărilor dintre raportul micro/macro filtratorilor. O rată mai scăzută de creștere (1,7 ori) s-a înregistrat în cazul biomasei bacterioplanctonului. Impactul maxim al eutrofizării (hipertrofia) este caracterizat de un input de energie exclusiv pe calea fitoplanctonului. Rata de ciclare a nutrienților de către fito și zooplancton a scăzut de 11, respectiv 1,1 ori, ca rezultat al schimbărilor în structura și relațiile trofice. Schimbarea raportului macrofite/fitoplancton a afectat compoziția substratului organic cu consecințe asupra bacterioplanctonului. Din 1991, datorită schimbărilor economice din Bazinul Dunării, a fost înregistrată o tendință de revenire a stadiului trofic al lacurilor, în primul rând observat la nivelul comunităților planctonice. Răspunsurile au constat în creșterea ratei de ciclare a nutrienților (fără a se atinge nivelul capacității maxime din perioada de referință). Până în anul 2001, zooplanctonul menține tendința descrescătoare începută în 1975, în timp ce bacterioplanctonul înregistrează valori semnificative ale ratei de ciclare a nutrienților, aceasta indicând prevalența proceselor de degradare în detrimentul celor de acumulare în biomasa proprie.

Cuvinte cheie: oferta energetică, stocare de nutrienți, Delta Dunării, eutrofizare, servicii ecosistemice.

INTRODUCTION

The research conducted in various types of ecosystems of the planet have no other purpose than to point out the characteristics of the impact of changes in the structure and functionality of trophic levels at spatio – temporal scale. Practically all aquatic ecosystems have been damaged by anthropogenic activities. Aquatic ecosystems are responsible for a wide variety of functions valuable to human society.

The various stressors have reduced both the quantity and quality of habitat for fish and wildlife and damaged aesthetic values important to tourism, as well. These trends are accompanied by the extinction or endangering of aquatic organisms and reduce many beneficial water uses, including drinking, swimming, and fishing (CAIRNS, 2006). These important services are provided by plankton communities in the aquatic ecosystems.

Danube Delta is a dynamic and heterogeneous complex of systems with different successional stages. The water systems (lakes, ponds, natural waterways, river arms) and wetlands represent 67-81% of the 442 300 ha of the Romanian delta (CRISTOFOR et al., 1994).

The plankton is part of the self-supporting ecological systems (natural, semi-natural and anthropogenic) and produces a wide range of services by absorbing and concentrating the radiant solar energy and cycling of the mineral elements.

The deciphering of the functional capacity and the mechanisms that realize the productivity of aquatic ecosystems involves the establishment of the principles that govern the rates of energy flow, the flow of nutrients and the control mechanisms in the field of stability (POSTOLACHE, 2006; RÎŞNOVEANU et al., 2008).

The functional capacity is defined as the extent to which a part of a wetland fulfills a specific function (VĂDINEANU et al., 1998; VĂDINEANU, 2004). The functional analysis is broadly the method to evaluate the provision of goods and services of the natural capital.

The estimation of the functional capacity of aquatic ecosystems requires the knowledge and understanding of the dynamics of plankton communities in turn modulated by controlling factors. We may state that changes in the specific composition, structure and function of phytoplankton act as a modulator for the behaviour of the whole food-web.

The development of knowledge on the role of the biodiversity components - populations (species, guilds or trophic levels) and communities contributes to the understanding of the functional capacity of ecosystems (functions and associated service fluxes).

In the evolution of the Danube Delta shallow lakes, significant structural and functional changes occurred in the planktonic communities, following the trophic state dynamics. As compared to the reference period, under the eutrophication pressure, profound changes in biodiversity and energy flow were observed.

The submerged macrophytes/phytoplankton ratio characterizing the natural status of the Danube Delta lakes (1975 – 1980, mesotrophic status) was altered by the acceleration of eutrophication process (1981 – 1995, eutrophic/hypertrophic status), with consequences on the entire food-web structure (MOLDOVEANU et al., 2010; ZINEVICI et al., 2004). The phyto- and zooplankton species richness decreased by 50%, impacting the production and nutrient recycling rates. The maximum impact occurred during the hypertrophic period, when the energy input was realized exclusively by the planktonic producers. These changes affected the flow of goods and services provided to the socio-economic systems.

The aim of the study was to emphasize the long-term changes in the ecological processes of planktonic communities and the impact on the flow of goods and services offered to socio – economic systems. The objectives were: energy flow assessment, assessment of nutrient storage capacity, evaluation of nutrient production, estimation of nutrient recycling rate.

MATERIAL AND METHODS

Study site and sampling

The Danube Delta Biosphere Reserve is located at 45°0′ N latitude, 29°0′ E longitude in the eastern part of Romania. The sampling campaigns were carried out in 1975 – 2001 period, in an extensive way, seasonally (Spring, Summer and Autumn) or monthly, on the water column, from Lake Roșu (Fig. 1). Lake Roșu is located at 45°05′21.81″ N latitude, 29°56′76. 42″ E longitude. It is the most representative freshwater lake of maritime delta, with an area of 1,445 ha, a water volume of 21.7 mil. cm and an average depth of 3 m.

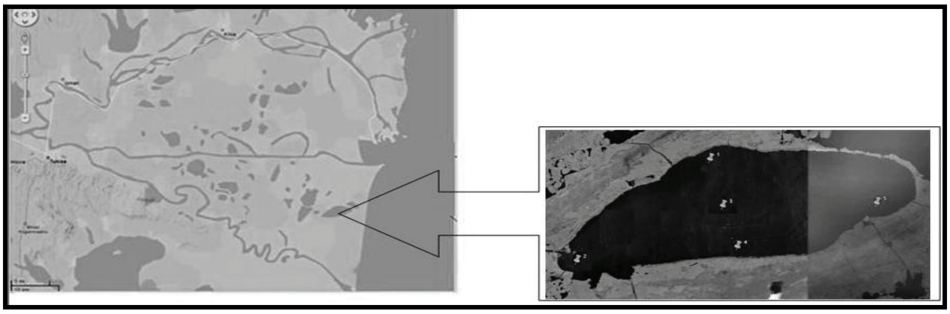

Figure 1. The map of the Danube Delta and sampling points of Lake Roșu (adapted after Google Earth).

Methods

The phytoplankton samples were collected without filtering, in 0.5 L bottles, preserved with 4% formaldehyde solution. The zooplankton samples were collected by filtering 50 litres of water using a Patalas-Schindler device (5 L) on water column through a 65 µm Ø mesh network, and preserved with 4% formaldehyde solution. Plankton species investigations: by inverted microscope using specific keys.

The phytoplankton and zooplankton biomass was assessed by volumetric and gravimetric measurements. The bacterioplankton biomass was estimated by direct counting and biovolume estimation.

The phytoplankton and bacterioplankton production was measured by Winkler method. The zooplankton production was achieved by the methods of Galkowskaja (Rotatoria), Ilkowska-Stankzykowska (for planktonic larvae of Lamellibranchia); Winberg, Pečen and Shushkina (Copepoda and Cladocera) described in EDMONDSON, 1974; EDMONDSON & WINBERG, 1971. The plankton content of nutrients (C, N, P) was assessed using conversion coefficients (WALVE & LARSSON, 1999; WINBERG, 1971).

RESULTS AND DISCUSSIONS

Although the provision of resources and services is an emergent property of the ecosystem, the achievement of ecological functions is related to direct or indirect contribution of many species/populations. Ecological processes supported by species/populations make the connection between biological diversity and ecosystem services. A key issue in determining the relative role of each species, in achieving specific functions and associated flow of services is to quantify the relative contribution of processes involved in the particular conditions.

There are multiple relationships between biodiversity and ecosystem services. In Table 1, there are presented the services provided by plankton starting from the classical ecosystem functions and the involving of biodiversity in shaping the ecosystem services.

In the eutrophication period, phyto and zooplankton species richness decreased with 50%, with effects on quality and quantity of production, as well as nutrient recycling rate. In Lake Roșu, the phytoplankton and zooplankton biomass increased 50 and 8 times, respectively, due to increased nutrient supply and changes of micro/macro filter feeders ratio. A low level of increasing (1.7 times) was recorded for the bacterioplankton biomass. During that period, the primary productivity increased 4 times and that of zooplankton 7 times by comparison with the reference state. In the new conditions, primary production efficiency (NPP/GPP) decreased from 80% in 1977 to 47% in 1986.

The energy offer of the three types of planktonic communities is consistent with that outlined in other lakes of the Danube Delta, with changes from one stage to another, due to the pressure of eutrophication. The energy supply of plankton expressed as biomass (kcal.m^{-3}) and production (kcal.m^{-3}/ 90 days), was considered part of the supply of the ecosystem services. It is basically the amount of energy made available by plankton to other trophy levels in the ecosystem. The supply of energy of the planktonic communities has a significant rising during the maximum impact of the eutrophication period; the phytoplankton had the prevailing role in the whole studied period (Table 2).

Table 1. The conceptual frame concerning the relationship between biodiversity and ecosystem services supply to Socio-Economic Systems.

The function of ecosystem	**TDM (tropho-dynamic-modules)**	**Services**	**The relationship between Biodiversity and Socio-Economic Systems (SES)**
Production	Phytoplankton Zooplankton Bacterioplankton	Biomass	BDV→SES
Regulation		Nutrient circulation Water quality	BDV→SES
Support		Biodiversity conservation	Genetic resources
Informational		Bioindicators Ecotourism Scientific and managerial information	Structural and functional parameters of TDM

During the reference period (1977 - 1978), the predominant role of primary producers in the ecosystems was hold by macrophytes. The gross productivity of phytoplankton was low, the turnover ratio was 1.54 and net primary production efficiency 80% (expressed by the ratio of net primary production/gross primary production), (theoretically this ratio can vary widely, 40% - 90%) (BOTNARIUC & VĂDINEANU, 1982; BOTNARIUC, 1999). These values demonstrate the natural state of the ecosystem, with a good efficiency of accumulation of net primary production, the organic substances usable by succeeded trophic levels.

The situation has radically changed since the 1980s. In the year 1986, high values of productivity were registered; the index P/B had the lowest value (0.19). In these circumstances, although the ecosystem productivity increased, the net primary production efficiency decreased by almost half (47%) compared to 1977.

Table 2. Energetic supply of plankton communities.

Period	**1975-1980**				**1985-1990**				**1995-2001**			
Plankton communities	Phyto	Zoo	Bact	**Σ**	Phyto	Zoo	Bact	**Σ**	Phyto	Zoo	Bact	**Σ**
Biomass (Kcal c.$m.^{-1}$)	1.54	0.51	0.84	**2.89**	38.47	4.16	0.93	**43.56**	20.81	1.25	1.88	**23.94**
Production (Kcal c.$m.^{-1}$/day)	1.47	0.06	0.18	**1.71**	6.40	0.45	0.41	**7.26**	6.15	0.11	0.84	**7.10**

The storage capacity of nutrients in the planktonic communities was increased in the hypertrophic period by 15 times (364.67 → 5,437.84 mg c.$m.^{-1}$) (Table 3).

Table 3. Nutrients storage capacity of plankton communities.

Plankton communities (mg c.m.$^{-1}$/day)	**1975-1980**			**1985-1990**			**1995-2001**		
	C	**N**	**P**	**C**	**N**	**P**	**C**	**N**	**P**
Phytoplankton	154	30.80	3.08	3847	769.40	76.94	2081	416.20	41.62
Zooplankton	51	12.75	1.32	416	104.00	10.81	125	31.25	3.25
Bacterioplankton	84	21.00	6.72	93	23.25	7.44	188	47.00	15.04
Σ	289	64.55	11.12	4356	896.65	95.19	2394	494.45	59.91

Nutrient transfer through the planktonic communities revealed an upward trend in comparison with the reference period (from 210.93 → 892.75 mg c.m.$^{-1}$/day) (Table 4).

Table 4. Nutrient production of plankton communities.

Plankton communities (mg c.m.$^{-1}$/day)	**1975-1980**			**1985-1990**			**1995-2001**		
	C	**N**	**P**	**C**	**N**	**P**	**C**	**N**	**P**
Phytoplankton	147	29.40	2.94	640	128.00	12.80	615	12.00	12.30
Zooplankton	6	1.50	0.15	45	11.25	1.17	11	2.75	0.28
Bacterioplankton	18	4.50	1.44	41	10.25	3.28	84	21.00	6.72
Σ	**171**	**35.40**	**4.53**	**726**	**149.50**	**17.25**	**710**	**146.75**	**19.3**

The input of energy in the ecosystem is due exclusively to phytoplankton (50%); the zooplankton has a low efficiency in directly energy uptake from phytoplankton (0.69%), accessing detritobacterial path (ZINEVICI et al., 2004); the DOM and POM compartments are overloaded with energy and most of it remains unused and is deposited in sediment (Fig. 2). In this type of ecosystem the "microbial loop" (bacteria - heterotrophic nanoflagellates - ciliates) has a special role in the flow of energy through the ecosystem (HART & STONE, 2000). Heterotrophic microbial communities represent a "drainage place" in which the energy contained in MOD representing 74% of the POC is transformed (through decomposition and mineralization) and a part of it returns to higher levels.

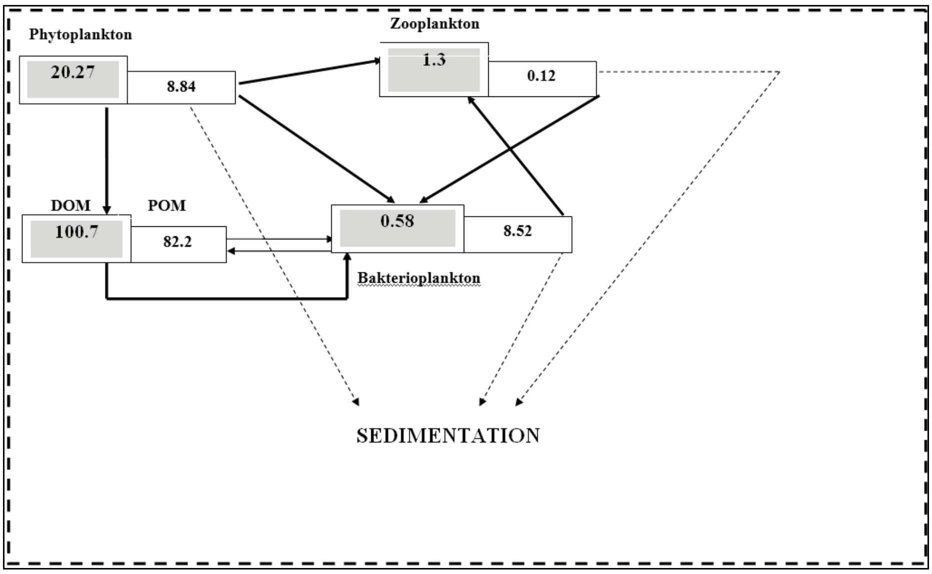

Figure 2. The diagram of energy flow in Lake Roșu (1999-2001)
grey boxes - biomass (kcal cm^{-1}); white boxes - production (kcal cm^{-1}/day).

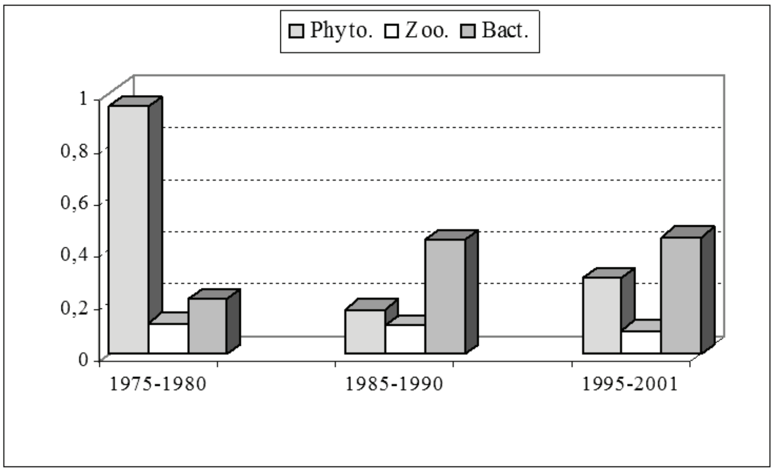

Figure 3. Nutrient cycling rate (P/B) in plankton communities.

Nutrient cycling rate, initially provided by the phytoplankton, is taken up by the bacterioplankton in the eutrophication period (Fig. 3). The replacement rate of biomass ("turnover rate") shows the speed of production, the replacement of mineral elements and the compensation of losses within a certain time (BOTNARIUC, 1999). The planktonic producers play a key role in nutrient cycling in the water, followed by decomposers; the zooplankton occupied the last place (PINTO-COELHO et al., 2005; WALVE & LARSSON, 1999; WETZEL, 1983; WINBERG, 1971).

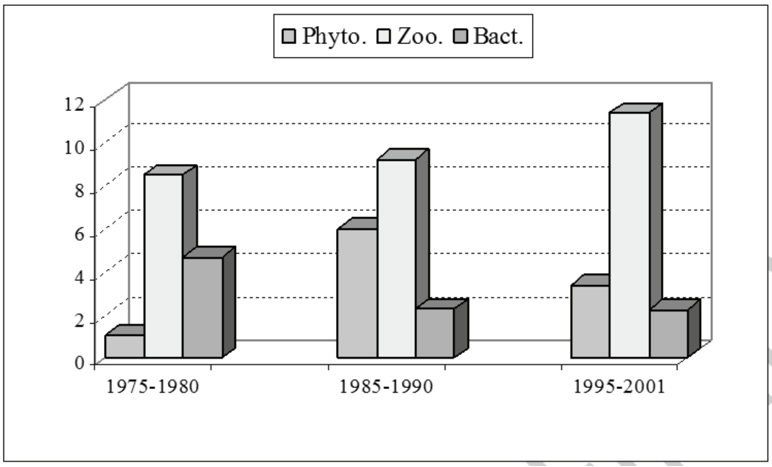

Figure 4. Nutrient cycling time (B/P) in plankton communities.

The phyto and bacterioplankton have a short time of generations which sustained well the cycling rate in comparison with the zooplankton (Fig. 4).

CONCLUSIONS

The phytoplankton played the prevailing role in the whole studied period in terms of energy. This fact leads to imbalances in the whole ecosystem.

The zooplankton has a low efficiency in directly energy uptake from phytoplankton, the DOM and POM compartments are overloaded with energy and most of it remains unused and is deposited in sediment.

Healthy ecosystems carry out a diverse array of processes that provide both goods and services to humanity. Over time and due to numerous destructive factors, the ecological services of plankton in the Danube Delta ecosystems have changed dramatically.

The ecosystem processes (productivity and nutrient recycling) result directly from the diversity of the biotic communities, which is in turn determined by the species composition and diversity.

These findings are especially useful for the administrative and policy makers in order to implement the suitable measures for the conservation of the Danube Delta, an inestimable complex of ecosystems.

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