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Review

The evolution of the eutrophication of the Palić Lake (Serbia)

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Eutrophication is a world-wide environmental issue. The Palic Lake is a shallow lake typical for the Pannonian plain. The Lake itself was in a very bad condition during the late sixties of the last century; polluted and hypertrophic. Due to inadequate water quality, it was dried out in 1971 and re-established in 1977 and since then its trophicity has been worsening. The lake has recreational purposes but it is also a collector for treated municipal waste waters coming from the lagoons for active sludge water treatment. The sewage discharges from rapidly developing towns in the watershed and the growing use of fertilizers in agriculture increased the nutrient load to the Lake in the last decades. A steady increase of phosphorus loading is the most important factor of the lake eutrophication. The result of the accelerated eutrophication is the enormous amount of sediment at the bottom of the Palic Lake. Therefore, in the lake that covers an area of 565 ha and volume of 10 million m^3, there was 1.900.160 m^3 of sediment. The sediment thickness varied from 0.3 to 1.2 m. In summer 2010, the recreational part of the lake (sector IV) was 1.311.356 m^3 of sediment, characterized with concentrations of total phosphorus (TP) of 2885 mg/kg, 4300 mg/kg total nitrogen (TN) and 39000 mg/kg total organic carbon TOC. The sediment of the Palic Lake was not loaded with high concentrations of heavy metals. Everything mentioned supports the fact that the restoration of this aquatic system is necessary and applied measures have to be grounded on the principles of ecoremediation technologies.

Key words: Eutrophication, Palic Lake, sediment, total N, total P.

INTRODUCTION

Lake eutrophication includes both natural and cultural eutrophication. The significant human disturbance of lakes did not occur until the 19th century and the cultural eutrophication appeared normally post-date 1900 (Battarbee, 1999).

Cultural eutrophication (excessive plant growth resulting from nutrient enrichment by human activity) is the primary problem facing most surface waters today. It is one of the most visible examples of human changes to the biosphere (Smith, 2003), affecting aquatic ecosystems from the arctic to the antarctic. Eutrophication has many undesirable side effects, major economic costs and transnational implications (Howarth et al., 2005; Pretty et al., 2003). Costs are about $ 2.2 billion annually as a result of eutrophication in the U.S. freshwaters (Dodds et al., 2009).

Eutrophication is the process of enhanced trophic status due to increased nutrient inputs (Moss et al., 1997). Today, eutrophication is the critical problem impairing surface water quality (especially in lakes and reservoirs) and the effective control of Lake eutrophication.

One of the major features of artificial eutrophication is that although, the consequences appear within the lake, the cause and most of the possible control measures lie in the surrounding region (Pei and Yong, 2003). Conse-

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quently, eutrophication management requires analysis of complex interactions between the water body and its surrounding region (Somlyody and Wets, 1988).

This process can induce abnormal phytoplankton increase, rapid decrease in water transparency, gradual decline in the macrophyte, quick deterioration of water quality and even final forfeiture of water function. Although, nitrogen (N) and phosphorus (P) have been assumed to be primarily responsible, phosphorus is the vital factor for freshwater systems (Aminot and Andrieux, 1996).

From the scientific, but also from the ecosystem management and legislative perspective, one of the fundamental problems in this context is the fact that, in many cases, long observational deposition data (monitoring) are not available to quantify the historical dimensions of anthropogenic contamination. In consequence, it is very difficult to assess the natural background levels and undisturbed conditions, the magnitude and dynamics of anthropogenic impacts and to evaluate success or failure of regulatory measures and technological improvements that are taken for emissions reductions and/or ecosystem restoration. This lack of monitoring data is especially critical in developing countries.

Republic hydrometeorological service of Serbia has monitored the water quality in 143 water flows in Serbia; 61 belong to Vojvodina region, according to government program, once per year. Nevertheless, even on these water bodies, the investigations were mostly conducted in a specific and limited time period without comprehensive and continual monitoring system (Svircev et al., 2008). Gained results on the other hand, were also not used properly in the management or exploitation activities (Gajin et al., 2003).

Sediments are generally recognized to play a prominent role in ecosystem cycling, as the top layer is intimately linked to surface waters through physical, chemical and biological processes. Lake sediments may provide suitable archives to decipher the history of local and regional pollution and eutrophication (von Gunten et al., 2009).

Lake sediments are powerful environmental archives and may provide quantitative historical records for most of the major types of pollutants (Bennion and Battarbee, 2007; Smol, 2008). Hence, the aim of this review article was to point out the problem of eutrophication of the Palic Lake and the necessity of its restoration.

LAKE CHARACTERISTICS

The Palic Lake is a shallow Pannonian lake, created a million years ago, when the wind created pits separated by dunes and recharged mostly by atmospheric precipitation. It is situated 8 km from Subotica, near the town of Palic. It covers an area of 3.8 km^2. The average depth of the lake is 2 m. Chronicle water scarcity for lake recharge is a lasting problem, caused by specific geological characteristics of the area; presence of sand and continental loss of high permeability. The mentioned natural characteristics and sewage water discharge in the lake caused intensive eutrophication and formation of thick sediment enriched by phosphorus and nitrogen.

The emerged problems caused a need for sanitation that finally happened in the period of 1972 to 1977, after which the lake appearance had been changed. The lake sediment was rearranged and built in lake shores, artificial islets and division walls. Hence, the Palic Lake was divided into 4 sectors (Figure 1); sector 1, was separated into three oxidation tanks and it is in fact still a part of water treatment system; sectors 2 and 3, were storage lakes that cover 85 and 81 ha, respectively. The idea of this reconstruction of the lake was following the retention of treated wastewater in sector 1 which lasts for approximately 25 days and then, it flows into storage lakes where further conditioning of treated water continues.

Sector 4, was the biggest part of the lake designed for recreational purposes. It covered around 372 ha with original depth of around 2 m, but today the depth of the lake varies due to the formation of thick sediment in some parts of the lake.

Excess water is evacuated through the Omladinsko Lake via a canal to the Ludas Lake, from where it is taken by the Keres streamlet to the Tisa River. The problem in the operation of the plant and achieving water quality, which will not impair and additionally accelerate the eutrophication process of the recipient, is the lack of tertial treatment within waste water treatment (removal of nitrogen and phosphorous compounds), massive hydraulic load of the plant and the inflow of not treated industrial effluents (Kurtes et al., 2009).

Today the Palic Lake is intensively used as a recipient for treated sewage water of the city of Subotica and it does not have an adequate recharge with water of acceptable quality. This lake is a very sensitive ecological system, loaded with concentrated and dispersed pollution.

NUTRIENT INPUT

Wastewater treatment plant (WWTP) of the city of Subotica was built in 1977 and the capacity of the plant was enlarged in 1983. Nevertheless, due to a number of omissions, treated wastewater were loaded with organic matter, nitrogen and phosphorus compounds and were discharged in the Lake. Besides, a great amount of untreated wastewater was discharged directly in the sector I of the Lake. Serious ecological situation of the Palic Lake influenced the beginning of the reconstruction and building of new capacities of the plant in 2004. Construction of new wastewater treatment plant began in year 2006. In year 2010, new wastewater treatment plant

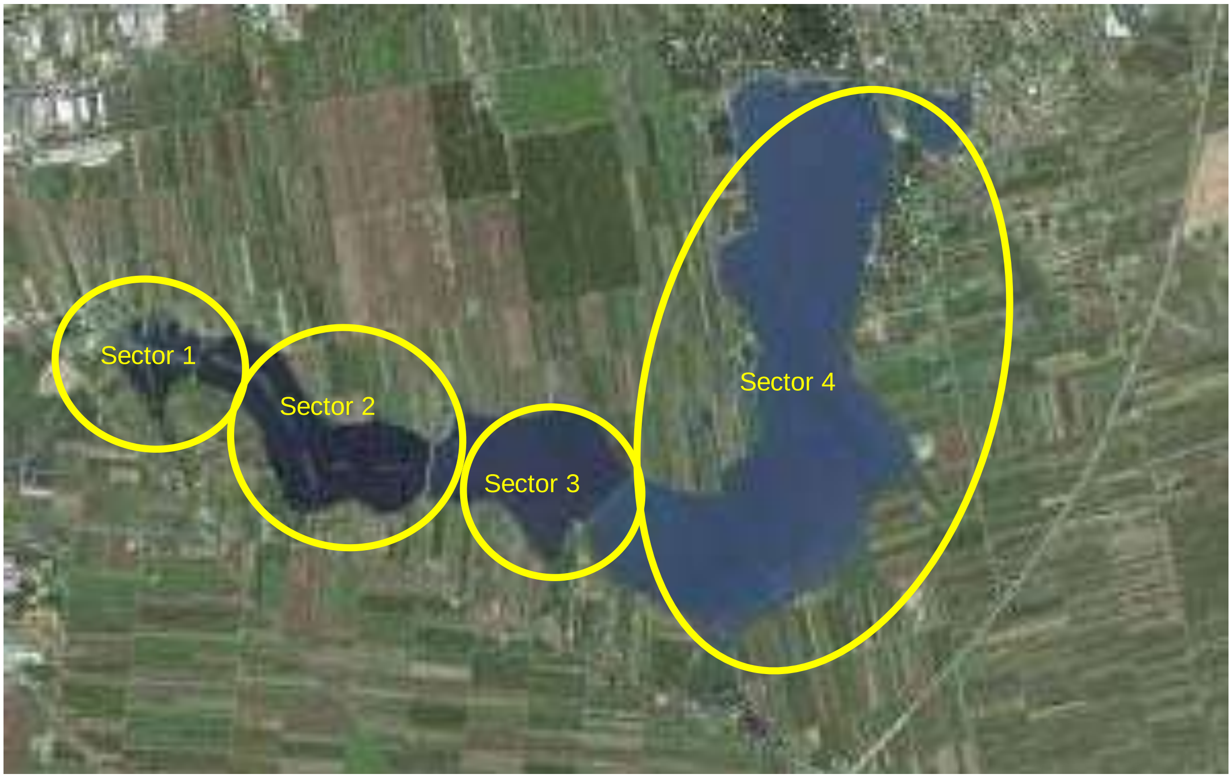

Figure 1. Aero-photo picture of the Palic Lake.

Table 1. The effluent quality.

Year	BOD (mg/l O_2)	Total N (mg/l)	Total P (mg/l)	TN:TP ratio (wt:wt)
1978	20.4	31.9	8.92	3.57
2007	20.9	30.5	4.20	7.2
2008	14.5	30.8	3.43	8.9
2010	< 6	11.048	0.84	13.15

has not been completed yet.

External inputs of nutrient-rich (N and P) and polluted waters are the major causes of Lake Eutrophication (Gulati and van Donk, 2002). This led to high phytoplankton biomass, turbid water and often undesired biological changes. The latter includes loss of biodiversity, disappearance of submerged macrophytes, fish stock changes, and decreasing top-down control by zooplankton on phytoplankton (Scheren et al., 2000; Sondergaard et al., 2003).

Effluent quality of annual mean for year 1978, 2007 and 2008 and mean for the period of April of May 2010, when WWTP started working with new capacity are presented in Table 1.

The main source of phosphorous for the Palic Lake is the discharged treated wastewater. Monitoring in the period of 1978 to 1998 pointed out that the mean value of total phosphorous was 9.01 g/m^3. For the same period, the average amount of treated wastewater released approximately 103 tons of phosphorus per year. In sector 4, the discharged was 2.9 g/m^3 of total phosphorous. If 10 million m^3 of treated wastewater flowed in sector 4 (the rest evaporated), 29 tons of phosphorus got into the Lake (Selesi, 2000).

WATER QUALITY OF THE PALIC LAKE

Several decades eutrophication has constituted the most serious problem facing water managers in densely populated areas (Smith, 2003). Turbid water, cyanobacteria blooms and loss of biodiversity cause problems in many lakes all over the world because of the increased external nutrient loading (Cooke et al., 1993).

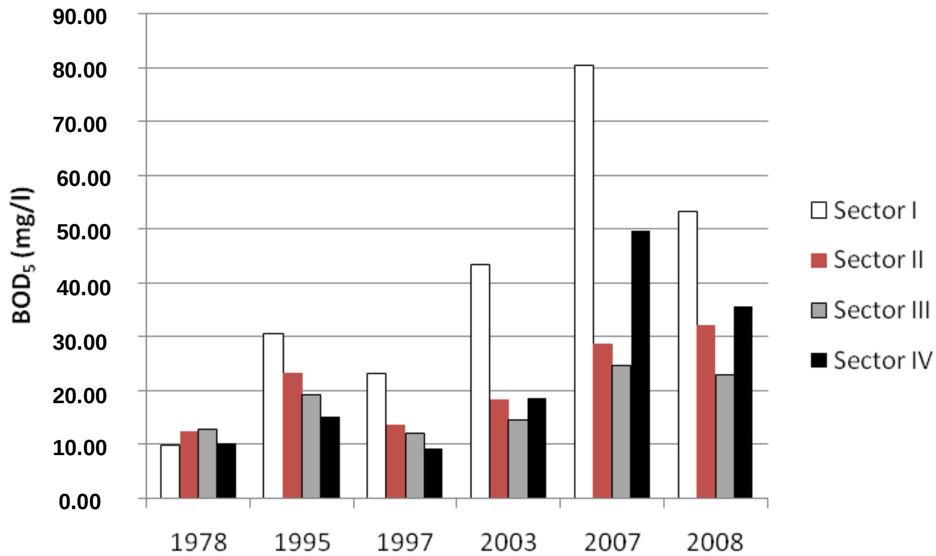

Figure 2. Annual mean of BOD across sectors of the Palic Lake.

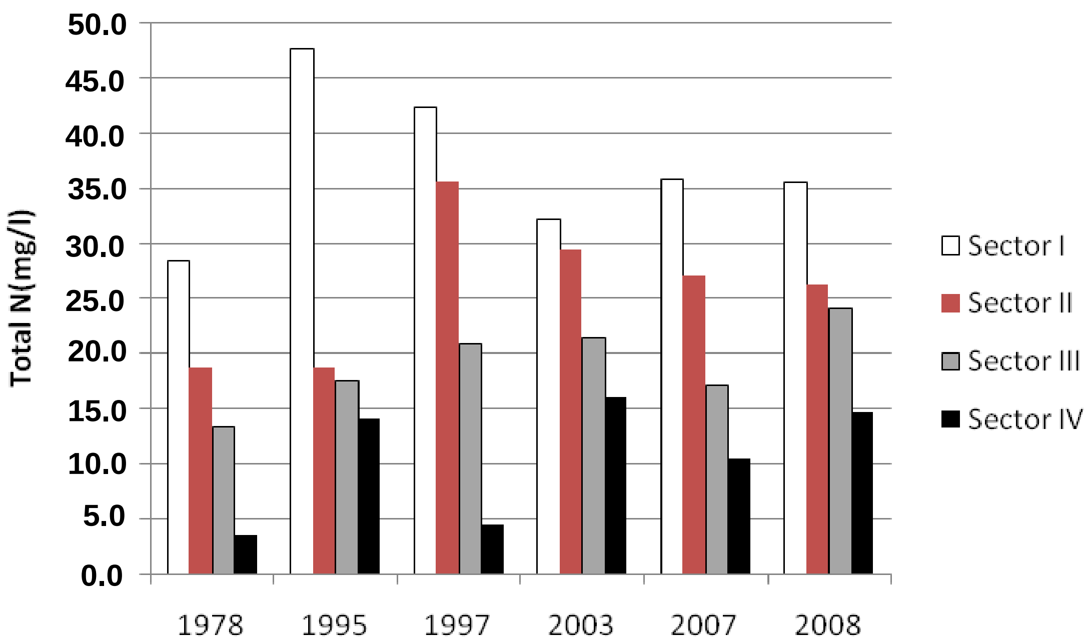

Figure 3. Annual mean concentration of total nitrogen across sectors of the Palic Lake.

In Europe, eutrophication is a serious environmental problem and an important issue in the implementation of the European water framework directive. This directive stipulates that good ecological quality, defined as a status deviating only slightly from undisturbed conditions and determined by the use of biological characteristics, should be achieved in all lakes by 2015.

General characteristics of water quality of the Palic Lake, such as annual average biochemical oxygen demand (BOD) and annual average concentrations of total nitrogen and total phosphorus in year 1978, 1995, 1997, 2003, 2007 and 2008 are displayed in Figures 2 to 5.

BOD values that express organic matter loading are rather high for surface water and point out high level of pollution (Figure 2). The highest values of chlorophyll a were noted in sector 4 of the Lake, from 2003 to date. These facts furthermore confirm the assumption of “algae explosion”, which was the consequence of nutrients

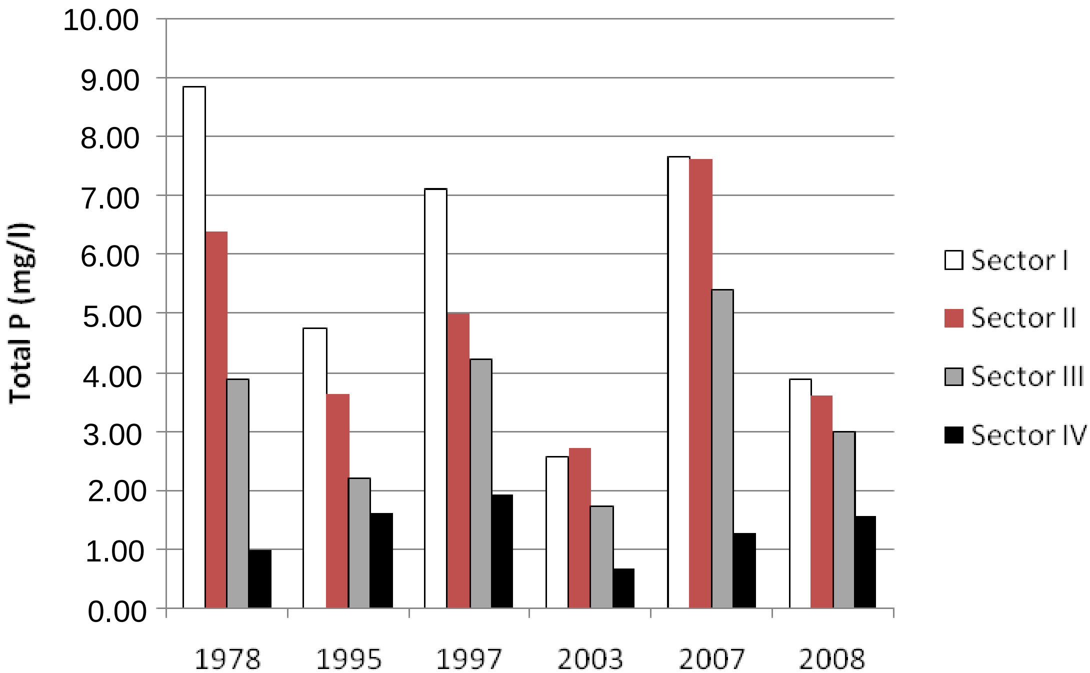

Figure 4. Annual mean concentration of total phosphorus across sectors of the Palic Lake.

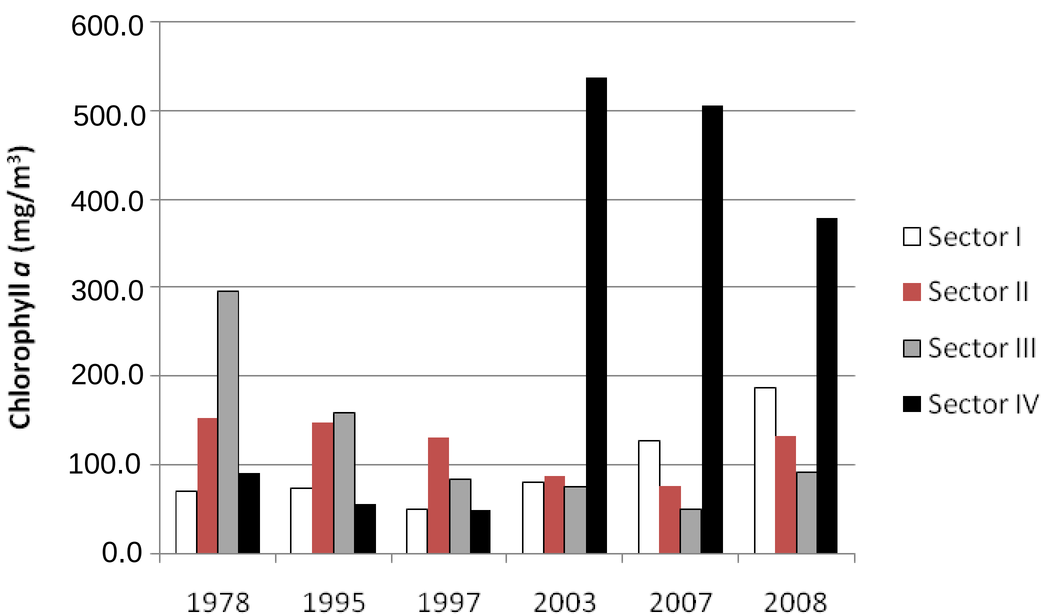

Figure 5. Annual mean of Chlorophyll a, across sectors of the Palic Lake.

overload in this part of the Lake (Figure 5). As a result of great algae reproduction water, clarity additionally decreased, water became cloudy and photosynthesis decreased as well as oxygen content, which further limited photosynthesis in deeper parts of the lake, especially in the part above benthos. All facts mentioned earlier influence changes in a food chain. The content of total nitrogen (TN) decreased from sector I to 4, but it remained rather high in the sector 4 (Figure 3).

Phosphorus (P) is a key nutrient for primary production in lakes, but in excess it can lead to eutrophication (Ahlgren et al., 2005). Concentrations of total phosphorus

Table 2. Water quality of the Palic Lake in June 2010.

Parameter	Sector 1	Sector 2	Sector 3	Sector 4
Turbidity (m)	1.5	0.6	0.3	0.2
pH	8.6	9	9.9	9.7
Conductivity 20°C (µS/cm)	1060	930	760	750
Total suspended solids (mg/l)	2	13	22	46
Chloride (mg/l)	163.7	85	93	94.3
Sulphate (mg/l)	434.5	89.9	81.3	81.7
NH_4^+-N (mg/l)	1.24	0.4	0.59	0.92
NH_3-N (mg/l)	0.15	0.12	0.47	0.53
NO_3^--N (mg/l)	0.902	0.373	<0.002	<0.002
NO_2^--N (mg/l)	5.7	2.2	0.2	0.4
Total N (mg/l)	7.93	2.98	2.52	2.88
Orthophosphate (mg/l)	1.39	1.07	0.06	<0.02
Total P (mg/l)	1.46	1.11	0.33	0.37
TOC (mg/l)	9.81	11.5	14.7	16.1
BOD_5 (mg/l)	2.2	4.5	8	7.2

Table 3. Quantity and quality of sediment in the Palic Lake.

Parameter	Area (ha)	Sediment quantity (m^3)	Total P (mg/kg DM)	Total N (mg/kg DM)	TOC (mg/kg DM)
The Palic Lake	565	1.900.160			
Sector 1	27	-			
Sector 2	85	293.097	15.655	5.450	54.950
Sector 3	81	295.707	12.900	3.000	36.590
Sector 4	372	1.311.356	2.885	4.300	39.000

(TP) in the Palic Lake generally varied between 8.84 and 0.65 mg/l, (Figure 4). The highest concentration was registered in sector 1 and the lowest in sector 4. In regards to the concentration of total phosphorous in the 4 sectors of the Lake during year 2008 and the volume of the Lake of 10 million m^3, the total inflow of phosphorous in the lake was calculated to be 121 t.

In year 2010, the concentration of phosphorous in sector 4 was 0.37 mg/l (Table 2), but referent (quality) value in this sector was 0.15 mg/l (Table 3). Concerning the total volume of the Lake, the calculated inflow of total phosphorous was 32.7 t. For the calculation convenience, 0.15 mg/l of TP concentration was used as the standard to reckon the needed water substitute rate (WSR) of the lake restoration (Jiang and Shen, 2006);

$$WSR = \frac{0.37 - 0.15}{0.37} \times 100 = 59.4\%$$

Therefore, 59.4% of the present water should be substituted by clean water for the lake to be restored.

SEDIMENT CHARACTERISTICS

Constant inflow of treated wastewater into the lake resulted in the formation of thick sediment and also determined its quality (Table 4). Nearly 2.000.000 m^3 of the sediment was spread across the lake bottom over the area of 565 ha, whose thickness varied from 0.3 to 1. 2 m.

Sediments accumulate phosphorus over long periods of time and the resulting concentrations of phosphorus in the upper few millimeters of the sediment can be much greater than the phosphorus content in the entire water column. The dissolved fraction of this large phosphorus store is constantly exchanged with the adjacent water. Because of the large phosphorus storage in the sediments, eutrophic conditions may continue for several years after phosphorus supply to the reservoir is considerably reduced.

Numerous studies have shown that high loading of phosphorus leads to high phytoplankton biomass, turbid water and often undesired biological changes. Lake sediments generally act as net sinks for phosphorus and also

Table 4. TN:TP, TC:TN,TC:TP, ratios in water column and surficial sediments of the Palic Lake in June 2010.

Parameter	Water sector				Sediment sector		
	4	3	2	1	4	3	2
TN:TP ratio (wt:wt)	7.78	7.63	2.68	5.43	1.49	0.23	0.35
TC:TN ratio (wt:wt)	5.59	5.83	3.85	1.23	9.07	12.1	10.1
TC:TP ratio (wt:wt)	43.5	44.5	10.3	6.7	13.5	2.83	3.51

as a source of phosphorus for the overlying water and biota (Baudo et al., 1990). Internal loading by sediment release plays a big role in the phosphorus status of lakes (Graneli, 1999; Scharf, 1999) and thereby, supports the trophic status of the lake.

Total organic carbon (TOC) and N can be used as proxies for primary production in the lake given the C/N ratio (as a measure of the ratio between aquatic and terrestrial sources of organic matter) and suggest predominantly aquatic sources and remain constant (Meyers and Teranes, 2001). C/N ratios (Table 4) values around 8 point out to predominantly aquatic biomass production, while values of N10 are related to increased terrestrial organic matter input to the lake.

TOC/TN ratios are low in the entire core suggesting that the organic matter was mainly derived from lacustrine authigenesis. Its concentration in lakes and rivers results from both external inputs and internal loading from the sediment, which can contribute phosphate to the overlying water at levels comparable to the external source; its release depends on the form of phosphate in the sediment. Most of sediment phosphorus is in the particulate form, dissolved P being only a few per cent of the total P. Not all the forms of phosphorus are bioavailable and therefore, likely to increase eutrophication (Ruban et al., 1998).

Heavy metals are widespread pollutants of great environmental concern as they are toxic, persistent and not degradable with serious ecological ramifications on aquatic ecology (Table 5). Humans have always depended on aquatic resources for food, medicines and materials as well as recreational and commercial purposes such as fishing and tourism (Phuong et al., 1998). In addition, aquatic ecosystems have significant impact on migratory bird species that use the water bodies as sanctuary and stop-over for food, breeding and nesting (Jumbe and Nandini, 2009).

The urban aquatic ecosystems are strongly influenced by long term discharge of untreated domestic and industrial wastewaters, storm water runoff, accidental spills and direct solid waste dumping. Sediments are integral and inseparable parts of the aquatic environments because they play a very important role in physicochemical and ecological dynamics; any change in toxic concentrations of heavy metal residues on the sediments will affect the natural aquatic life support systems.

EUTROPHICATION AND INFECTIOUS DISEASE RISK

The supply of nutrients can directly and indirectly limit the metabolic activity of heterotrophic microorganisms. For example, there is evidence for direct positive effects of N and P on bacterial growth (Farjalla et al., 2002) and accordingly, the total bacterial biomass is strongly correlated with concentrations of total phosphorus in freshwater and marine ecosystems.

There might also be direct linkages between eutrophication and disease risk. Potential linkages between pathogens and nutrient availability could have important implications for managing human health in areas of lakes and oceans that have significant bathing-related activity. Recreational use of waters can spread fecal-oral viruses (enteroviruses, hepatitis A viruses, rotaviruses and others) that cause a broad range of gastrointestinal, respiratory, eye, nose, ear and skin infections.

Water-related diseases are a major cause of human morbidity and mortality worldwide (WHO, 2003) and recent evidence suggests that diseases can cause major impacts among aquatic organisms (Harvell et al., 2004). Clearly, biological waste disposal activities such as manure applications to crop land can simultaneously increase the loading of phosphorus, nitrogen and potentially hazardous coliforms bacteria to surface waters (Hofmann and Beaulieu, 2001).

However, enhanced nutrient loading alone might also influence the abundance, composition, virulence and survival of pathogens that are already resident in aquatic ecosystems (Smith, 2003). For example, increased nitrogen and phosphorus availability enhances the replication rate of aquatic viruses (Wilson et al., 1996).

Another potential nutrient-pathogen interaction involves changes in food quality; if eutrophication influences the nutrient content of food consumed by host organisms, then changes in host nutrition could alter host-pathogen dynamics and the ultimate outcome of infection (Smith and Schindler, 2009). Eutrophication can also influence the abundance of pathogens indirectly by modifying the abundance and distribution of their hosts and vectors(Table 6). For example, eutrophication-driven increases in host abundance, increases the contact rate between infected and uninfected Individuals (Lafferty et al., 2004). Johnson and Carpenter (2008) emphasized the need to integrate scientific experiments and ecological modelling

Table 5. The quality of sediment across sectors of the Palic Lake; heavy and toxic metals (mg/kg DM).

Heavy metal	Sector 2	Sector 3	Sector 4	Dutch sediment quality guidelines	
				Target value	Maximum permissible concentration
As	71.2	37.6	38.6	29	55
Cu	84	23.4	18.9	36	73
Zn	151	59.2	41.2	140	620
Cr	189	52.7	26.8	100	380
Cd	1.1	0.5	0.4	0.8	12
Ni	85.9	29.5	23.1	35	44
Pb	29.3	16.4	15.6	85	530
Hg	<0.2	<0.2	<0.2	0.3	10

Table 6. Microbiological analysis of sediment samples.

Parameter	Sector 2	Sector 3	Sector 4
Sediment thickness	20 cm	20 cm	30 cm
Parameter	Value	Value	Value
Total of aerobic mesophilic bacteria in 1 g	4000	20000	8000
Fecal coliforms in 1kg	0	24000	3800
Total of coliform bacteria in 1 kg	0	24000	3800
Fecal Streptococci in 1 g	negative	negative	negative
Sulfite-reducing clostridia in 1 g	30000	20000	6000
Other isolated microorganisms	*Saprophytic cocci, Bacillus* sp.	*E. coli, Bacillus* sp.	*E. coli, Bacillus* sp.

modeling to identify thresholds and feedbacks in the interactions between nutrient loading and host-pathogen dynamics. However, little is known about feedbacks in the other direction; can epidemic disease in aquatic systems exacerbate eutrophication? Carefully designed studies are needed to clarify eutrophication-pathogen interactions and to assist in the further development of disease risk models (Smith and Schindler, 2009).

RESTORATION OF THE LAKE

Restoration of severely eutrophic, shallow lakes often involves a systematic treatment, starting with the control of external nutrient inputs and internal nutrient release, followed by biomanipulation and finally, the stabilization of a macrophyte-dominated lake (Madgwick, 1999).

Many techniques are available for the improvement of water quality within the body of reservoirs; artificial mixing and oxygenation, sediment removal, sediment aeration, sediment covering, phosphorus inactivation, biomanipulation (fish management), hydraulic regulation, algaecides, light reduction, macrophyte control and ecoremediation. Ecoremediation presents a sustainable use of natural and creation of artificial ecosystems for environmental protection and restoration with a special importance for the Vojvodina water ecosystems, due to their seasonal pollution patterns and overall lack of fresh water in the Republic of Serbia (Svircev et al., 2008).

The environmental protection agency (EPA, 1980) of USA investigated the remedy situations of 28 lakes. The data showed that in the restoration of lake, every $1 investment will benefit $4.15. Therefore, in both environment protection and economic benefits, it is necessary and advantageous to invest a certain amount of money for the restoration of polluted lake.

The eutrophication of shallow lakes has increased in recent years, with the major phenomenon of overgrown algae, low water clarity, oxygen deficiency, bad smell and polluted sediment slurry deposit. As known, cutting down the nutrients in lakes is the basic measure against eutrophication; however, it is still difficult to improve the lake environment in a shorter period even when the external pollution sources have been controlled efficiently. A feasible option is eliminating the internal pollution source by dredging the polluted sediments and recovering the aquatic vegetation by improving their habitat conditions (Zhang et al., 2010).

Cultural eutrophication has become the primary water quality issue for most of the freshwater and coastal marine ecosystems in the world. However, despite extensive research during the past four to five decades, many key questions in eutrophication science remain unanswered. Much is yet to be understood concerning the interactions that can occur between nutrients and ecosystem stability, whether they are stable or not, alternate states pose important complexities for the management of aquatic resources (Smith and Schindler, 2009).

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