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NUTRIENT INPUTS, TROPHIC STATUS AND WATER MANAGEMENT CHALLENGES IN THE TRANSBOUNDARY LAKE SKADAR/SHKODRA, WESTERN BALKANS

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Abstract - A transboundary water quality-monitoring program was conducted in 2007-2009 to investigate the trophic status and nutrient budget of Lake Skadar/Shkodra, which is a large, shallow lake shared by Albania and Montenegro. The parameters included, amongst others, total phosphorus (TP), total nitrogen (TN), suspended particulate matter, chlorophyll a, phytoplankton, transparency, temperature and oxygen levels. In addition, hydrological data were scrutinized. The results show that inputs from the tributaries amounted to 176 tons of TP and 3 200 tons of TN, with annual area specific loads of 50-70 kg/km^2 of TP and 950-1100 kg/km^2 of TN. Despite relatively high inputs, data from the lake indicate that it is presently in a mesotrophic condition, probably due to its large volume and low water residence time. It is assumed that water bodies in the Western Balkans are under increased environmental pressure due to the economic and societal development in the region. In our study, interactions with stakeholders revealed that this also applies to Lake Skadar/Shkodra, but at the same time, the stakeholders suggested a number of mitigation options that can improve the situation. In addition, harmonized transboundary monitoring and increased data transparency were deemed important to improve future decision-making.

Key words: Eutrophication, monitoring, Skadar/Shkodra, Western Balkans, transboundary water management.

INTRODUCTION

Eutrophication in European lakes has been a major concern for decades (Schindler, 2006), and therefore monitoring has been carried out on a regular basis in many of the lakes. However, a compilation of data on 5 000 lakes in 20 European countries revealed that information related to eutrophication is lacking for certain types of lakes on this continent, for instance in the Balkan and Mediterranean regions (Moe et al., 2008)**.** This shortage of data regarding the current environmental status of water bodies is even more alarming when considering the rapid economic development in the Western Balkans. Because of the political changes that occurred in this region in the 1990s, and despite the recent economic recession in Europe, it is expected that the environmental pressure from sectors such as agriculture, tourism and hydropower will increase (Bockheim, 2001; Turner, 2006; COWI, 2009). Consequently, to ensure that adequate management options will be available in the future, it is extremely important to compile information on current conditions as soon as possible and before any major modifications are implemented in the catchment areas.

It is also essential for managers of water resources in the Western Balkans to take into account that 13 river basins and 4 large lakes in this region are shared by two or more countries (UNESCO, 2004). Such transboundary management of water resources requires cooperation between different management structures and practices (Bärlund, 2002; Faloutsos et al. 2006; Gooch and Stålnacke, 2006), and access to reliable data is deemed important for the successful management (Timmerman and Langaas, 2004, 2005).

Several investigators have pointed out that the lack of data has limited our understanding of the functioning of shallow Mediterranean lakes (Beklioglu et al., 2007; Özen et al., 2010), which, unlike similar lakes located further north in Europe, are often characterized by substantial fluctuations in water levels that affect ecological processes. The large and shallow Lake Skadar/Shkodra, shared by Albania and Montenegro, was used as a case in the present study. According to Keukelaar et al. (2006), reliable data on this lake are seriously deficient, which can be partly attributed to the unwillingness to share existing data. This can be linked to the cost of data collection and therefore the economic value of the data. However, Keukelaar and colleagues also indicated that it has often been difficult to use the available data due to lack of information on the methods, sampling dates and sampling stations.

Within the context of the EU Water Framework Directive (WFD) (EC, 2000), lakes are divided into types according to factors such as geographical location, alkalinity, pH, color, size and elevation above sea level (EC, 2008). However, large lakes often exhibit striking individual differences that make them difficult to compare (Nõges et al., 2008), and hence it is deemed important to have access to reliable data on such lakes.

Considering the transboundary management efforts of interest in our investigation, in May 2003 the Ministers of the Environment in Albania and Montenegro signed a Memorandum of Understanding for the Protection and Sustainable Development of Lake Skadar/Shkodra. This has been followed to a certain extent by other measures, such as the Strategic Action Plan (SAP, 2007). However, much work remains to be done in this area, particularly regarding systematic and transboundary monitoring programs. The general aim of the present study was to contribute data to this endeavor by conducting a three-year transboundary monitoring of Lake Skadar/Shkodra and its tributaries and outlet river. The main goal was to assess nutrient inputs and the trophic status of the lake, and to interact with stakeholders to discuss possible solutions to management challenges and identify future threats to the lake ecosystem.

Case study area

The lake in focus in our study (Fig. 1) is called Skadar or Skadarsko in Montenegro, Shkodra in Albania, and Skutari in Italy. However, for the sake of simplicity, the name Lake Skadar will be used in the rest of this paper. Lake Skadar is located about 20 km from the Adriatic coast and approximately 5 m above sea level, and the mean depth is about 5 m but can be as much as 60 m in some isolated sublacustrine groundwater springs. The water level in the lake fluctuates between dry and wet periods, causing variations in the surface area from 350 to 500 km^2 and in the volume from 1.7 to 4.0 km^3. This has resulted in a wetland with an area of about 150 km^2, which is an important habitat for birds, fish, invertebrates, amphibians and mammals, of which some species are rare and endangered (Keukelaar et al., 2006; Karaman and Beeton, 1981). This area is listed as one of 24 transboundary wetland sites of international value (EEA 1995), and it has two Ramsar sites (nos. 184 and 1598).

The University of Montenegro measured the calcium levels in the lake in 2003-2006. The results show an average concentration of 40-45 mg/l, with very little variation (unpublished data). Based on the above and in accordance with the WFD typology system, Lake Skadar can therefore be classified as a very large (>100 km^2), shallow, and calcareous lowland lake of the Mediterranean or Balkan region.

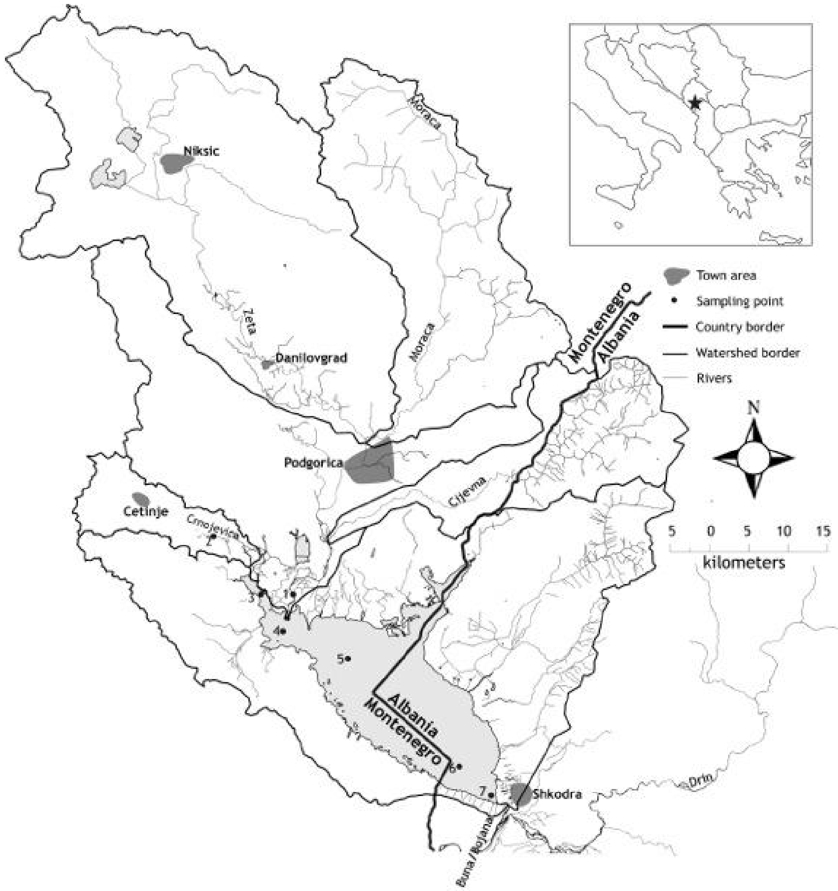

Fig. 1. Map of Lake Skadar and its catchment area showing the locations of the sampling stations (numbers).

Lake Skadar has a catchment area of 5 234 km^2, and its main tributary is the Morača River (3 449 km^2), which drains large parts of Montenegro, including the agricultural Zeta plains and the capital city of Podgorica, before it enters the northwestern part of the lake. The Crnojevića River, with a catchment of 147 km^2, is another tributary that enters Lake Skadar in the northwest. Most of its water flows underground in karstic bedrock, and the river emerges from a cave spring at a distance of about 10 km from the lake. The northwest area of the lake is divided from the rest by a motorway consisting mainly of road fill material and a short bridge. The Crnojevića River enters the lake upstream of this artificial divide, whereas the delta of the Morača delivers water both up- and downstream of the bridge.

Lake Skadar empties into the Buna/Bojana River, which converges with the Drin River only a few hundred meters downstream of the outlet. The Drin River has a total drainage area of about 14 000 km^2 and during high water discharge, it can impede outflow from the lake (Keukelaar et al., 2006; Van Welden et al., 2008). The Drin River drains into the Adriatic Sea.

MATERIALS AND METHODS

In transboundary water bodies, it is often useful to have a common system for monitoring water quality (Timmerman and Langaas, 2004, 2005; Literathy, 1997; László, 2002), and even though Albania and Montenegro are not members of the European

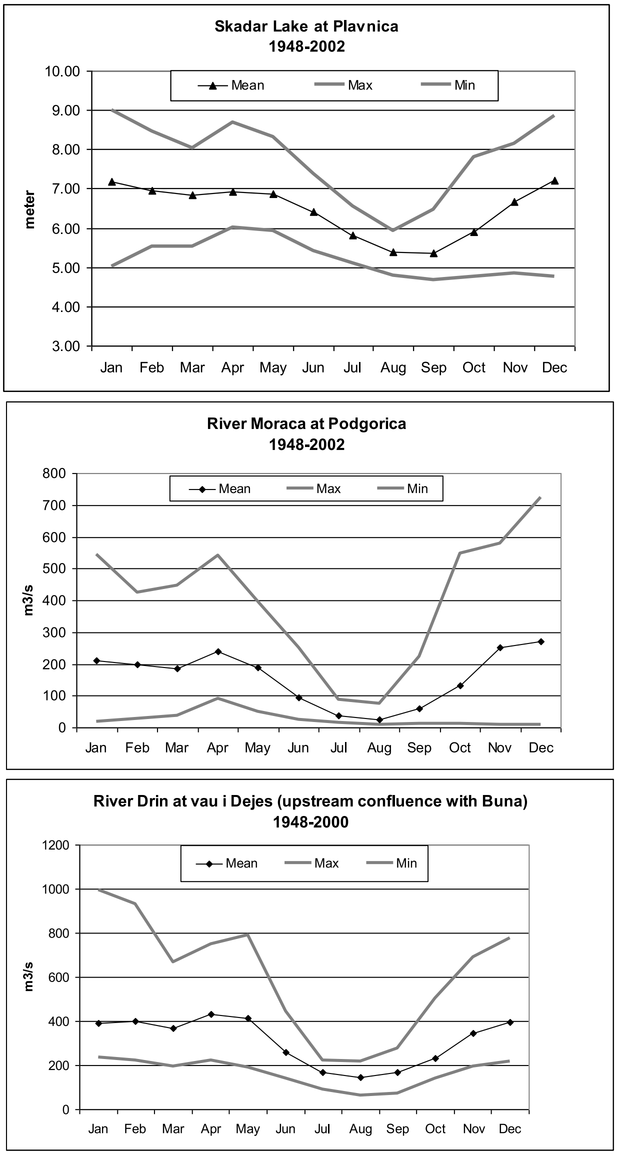

Fig. 2. Monthly mean, minimum (min), and maximum (max) water levels in Lake Skadar at Plavnica in 1948–2002 (upper chart); monthly mean, min, and max water discharge in the Moraca River at Podgorica (middle chart) and in the Drin River at Vau i Dejes (upstream confluence with the Buna/Bojana River).

Union, the WFD (EC, 2000) can provide a valuable methodological basis. Therefore, in the present project, this directive was used to guide the design of the monitoring set-up, which is why total phosphorus (TP) and total nitrogen (TN) were analyzed rather than the nutrient fractions that are usually evaluated in this region, and phytoplankton was counted by volume instead of by number.

Several studies have shown that harmonized transboundary monitoring can be hampered by practical constraints (Literathy, 1997; Parr et al., 2002; Skarbøvik et al., 2010). The main challenge in our investigation proved to be differences in laboratory performance. Inasmuch as inconsistencies were found in the nutrient analyses carried out in 2007, inter-laboratory comparisons were performed. Only small deviations were found in data on suspended particulate matter (SPM) and chlorophyll a, whereas large discrepancies were noted in the results for TP and TN, probably because these parameters are seldom analyzed in this region (Skarbøvik et al., 2010; Kagalou and Leonardos, 2009). This led to the decision not to use the results of total nutrient analyses from 2007, and the samples collected in 2008 and 2009 were sent to a single accredited laboratory for analyses of TP and TN. Originally, this monitoring program was planned to last only two years. However, in light of the relatively poor outcome of the 2007 monitoring, the sampling was continued in 2009, although at fewer stations.

Monthly sampling was performed in Lake Skadar during the growing season (March/April-October). In the rivers, sampling was done throughout the year at monthly intervals with additional sampling during flood events in the tributaries. The sampling sites are shown in Fig. 1, and the sites and the parameters analyzed are presented in Table 1.

An earlier study by Rakocevic-Nedovic and Hollert (2005) had demonstrated that Lake Skadar is well mixed (not stratified), and thus water samples from the lake were collected at only one depth (2 m). In the rivers, the samples were taken in the middle of the stream in locations with good mixing of the water. The sampling bottles were cleaned with acid (HCl) and washed three times in the lake water before use. As a preservative, 2 ml of 4 M H_2SO_4 was added to the samples before TP and TN analyses. TP was analyzed according to ISO 6878 (the ammonium

Table 1. Overview of parameters monitored at seven stations in Montenegro and Albania in 2007–2009.

St. no	Station name/description	Country*	Year of monitoring	Parameters
1	Morača River	MN	2008, 2009	TP, TN, SPM, pH, conductivity, fecal bacteria
2	Crnojevića River	MN	2008, 2009	
3	Lake Skadar, upstream of motorway crossing	MN	2007, 2009	TP, TN, SPM, pH, conductivity, fecal bacteria, chlorophyll a, transparency, oxygen, temperature
4	Lake Skadar (Vranjina)	MN	2007, 2008, 2009	
5	Lake Skadar (pelagic)	MN	2007, 2009	
6	Lake Skadar (pelagic)	AL	2007, 2008	TP, TN, SPM, pH, conductivity, fecal bacteria, chlorophyll a, transparency, oxygen, temperature, phytoplankton biomass
7	Buna/Bojana River	AL	2007, 2008	TP, TN, SPM, pH, conductivity, fecal bacteria, oxygen, temperature

*MN, Montenegro; AL, Albania.

Table 2. Annual water balance of Lake Skadar

Site	Area	Qmean	Volume
	km^2	m^3/s	mill m^3
Morača River	3,361	205	6,466
Crnojevića River	147	9	283
Remaining catchment area	1,639	100	3,153
Total to lake	5,234	319	10,059
Proportion of input water from groundwater wells		~54	~1,700
Buna/Bojana River outflow		~310	~9,780
Lake Skadar (annual average)	425		2,850

Table 3. Nutrient budget of Lake Skadar in 2008

Site	SPM (tons/yr)	TP (tons/yr)	TN (tons/yr)
Morača River	50,000	165	3,200
Crnojevića River	1,430	11	160
Sum of tributaries	77,430	176	3,360
Buna/Bojana River	(insignificant)	85	2,500
Lake retention	(high)	91	860

molybdate spectrometric method) and TN according to ISO 11905-1 Part 1 (a technique using oxidative digestion with peroxodisulfate).

For analysis of chlorophyll a, samples were transported to the laboratory immediately after collection and then filtered, and the filters were kept frozen until analyzed by the ISO 10260 method. To analyze SPM, water samples were passed through glass-fiber filters (Whatman GF/C), which were subsequently dried at 105°C for one hour and then weighed. To assess phytoplankton, samples were preserved with Lugol's solution, and phytoplankton biomass was determined in Norway, because that technique is rarely used by our Balkan partners. Unfortunately, a number of these samples were damaged in transport, and hence some of the flagellates were partly dissolved and difficult to identify.

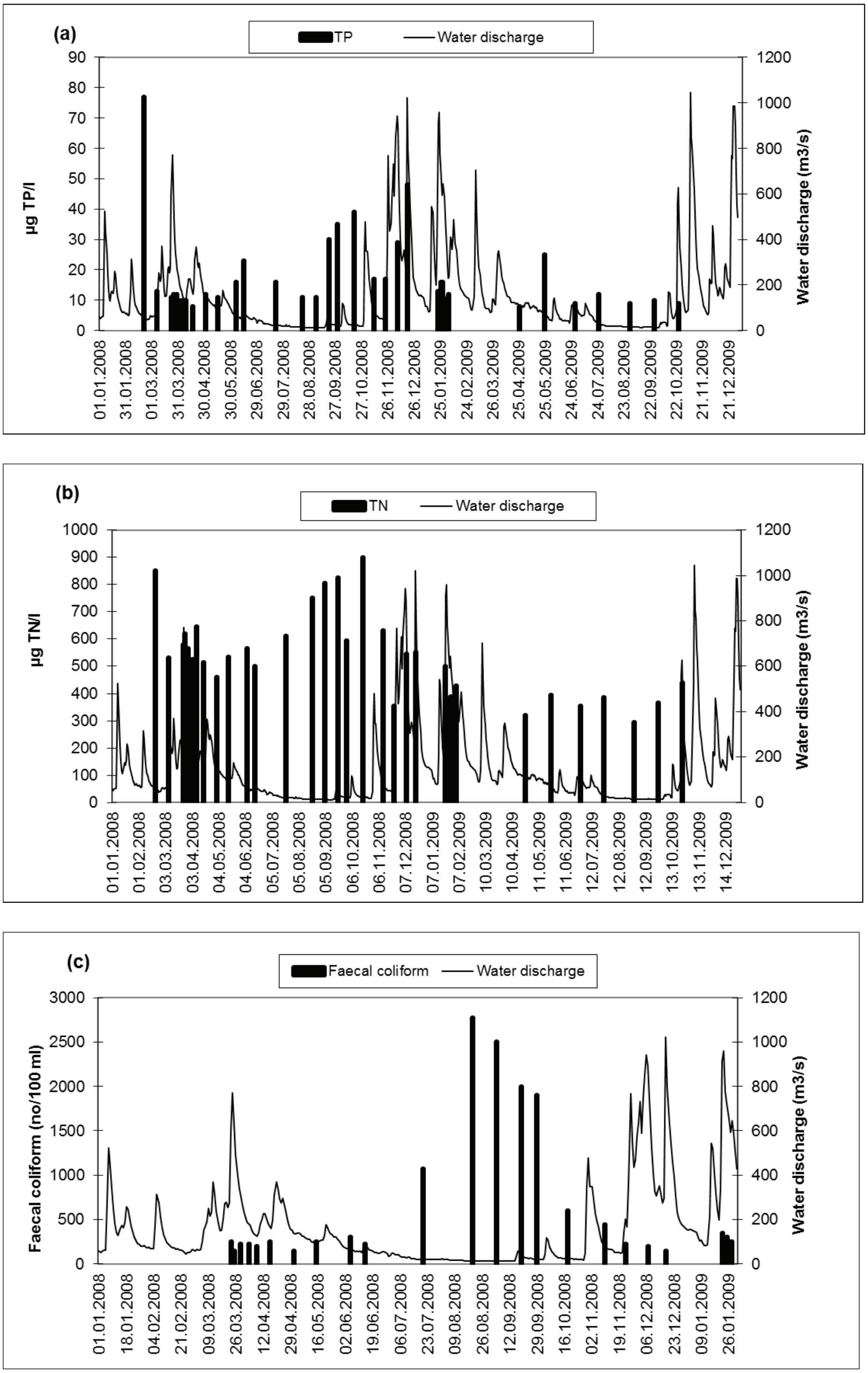

Fig. 3. Water discharge and concentrations of total phosphorus (TP) (a), total nitrogen (TN) (b), and fecal coliform bacteria (c) in the Morača River in 2008 and 2009.

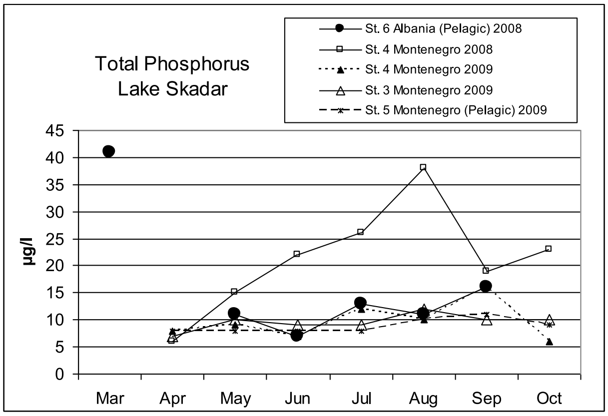

Fig. 4. Total phosphorus concentrations at four sampling stations in Lake Skadar in 2008 and 2009.

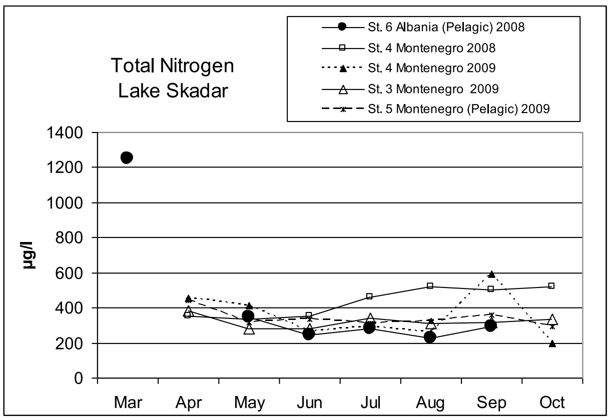

Fig. 5. Total nitrogen concentrations at four sampling stations in Lake Skadar in 2008 and 2009.

In situ measurements were performed using sensors for oxygen, temperature, conductivity and pH. Transparency was measured using a Secchi disc.

Nutrient and sediment loads were calculated using linear interpolation to obtain daily estimates of nutrients and sediment concentrations. The resulting daily concentrations were multiplied with daily water discharges in order to attain loads. Hydrological data were obtained from the hydrometeorological institutes in each country.

A stakeholder questionnaire survey was conducted in 2007-2008. In all, 200 people in Albania and 80 in Montenegro were interviewed, and the researchers filled in the responses in the questionnaire. The individuals were randomly selected and included both local residents and tourists. Furthermore, a transboundary workshop was held in 2008 for 22 participants, including managers, scientists, policy makers and end-users from several sectors in both Albania and Montenegro. The participants were divided into groups in which they discussed the main pressures, conflicts and problems related to the use and management of Lake Skadar and its catchment area.

RESULTS

Hydrology, water balance and residence time

The monthly mean water levels in 1943-2002 in Lake Skadar fluctuated as much as 4 m, which is quite substantial for a lake with a mean depth of only 5 m (Fig. 2a). The water level is usually highest in the spring due to a combination of rainfall and snowmelt in the mountains, and lowest during late summer, and this pattern is reflected in the water discharges from both the Morača River (at Podgorica) and the Drin River (at Vau i Dejes, immediately upstream of the confluence with Buna/Bojana River) (Figs. 2b and c).

Values for total flow in the Morača River at Podgorica were 4 670, 4 550 and 5 314 million m^3 in 2007, 2008 and 2009, respectively, whereas average flow during the period 1948-2004 was 5 014 million m^3. Nonetheless, the average daily water levels in Lake Skadar were similar in 2007 and 2009 (169 cm at the station at Plavnica) but significantly lower (134 cm) in 2008; this lack of agreement with the inflow can probably be explained by the influence of the Drin River.

The water balance was computed by using information from previous calculations (Prohaska and Ristic, 2004; Knezevic, 2004) along with data on monthly mean water discharges in 1983-2002 at Morača River at Podgorica. The resulting water balance (Table 2) indicated that the water in Lake Skadar is renewed 3.5 times a year. This corresponds to a water residence time of about 100 days, which is presumably relatively uniform throughout the lake,

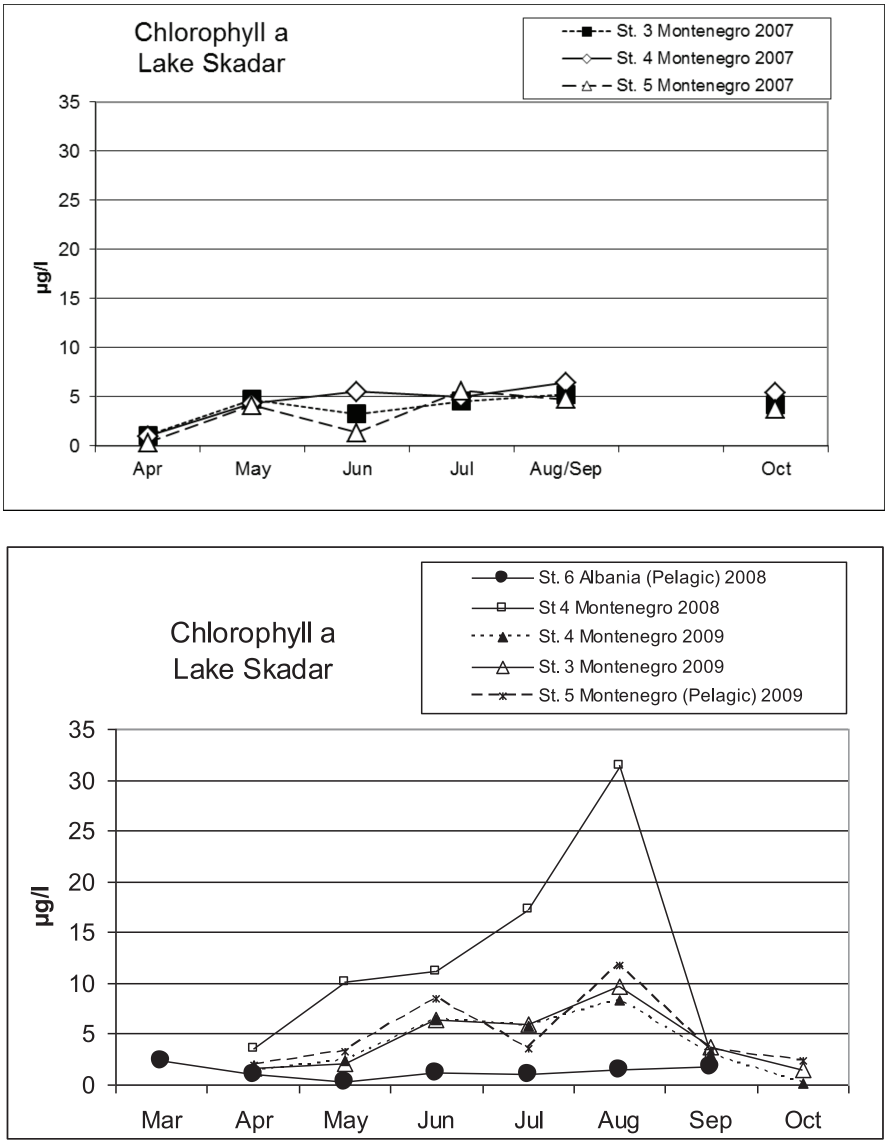

Fig. 6. Chlorophyll a concentrations at different sampling stations in Lake Skadar in 2007 (upper panel) and in 2008 and 2009 (lower panel).

except in the area upstream of the motorway, where the water may reside longer.

River water quality

In the tributaries, the pH was relatively stable, varying between 8 and 8.5, and there was little variation in the conductivity (average 240 µS/cm). In the Morača River in 2008 and 2009, levels of TP and TN ranged from 8 to 77 µg/l and 240 to 900 µg/l, respectively (Figs. 3a, b), and concentrations of SPM varied between 12 and 60 mg/l. The SPM levels were highest during high flows (R^2=0.7 for a polynomial curve), whereas the TP levels were high during both low and high flows. Furthermore, there was a poor correlation between TP and SPM (R^2=0.016), which suggests that the phosphorus was derived chiefly from sewage and less from eroded agricultural soil. This conclu-

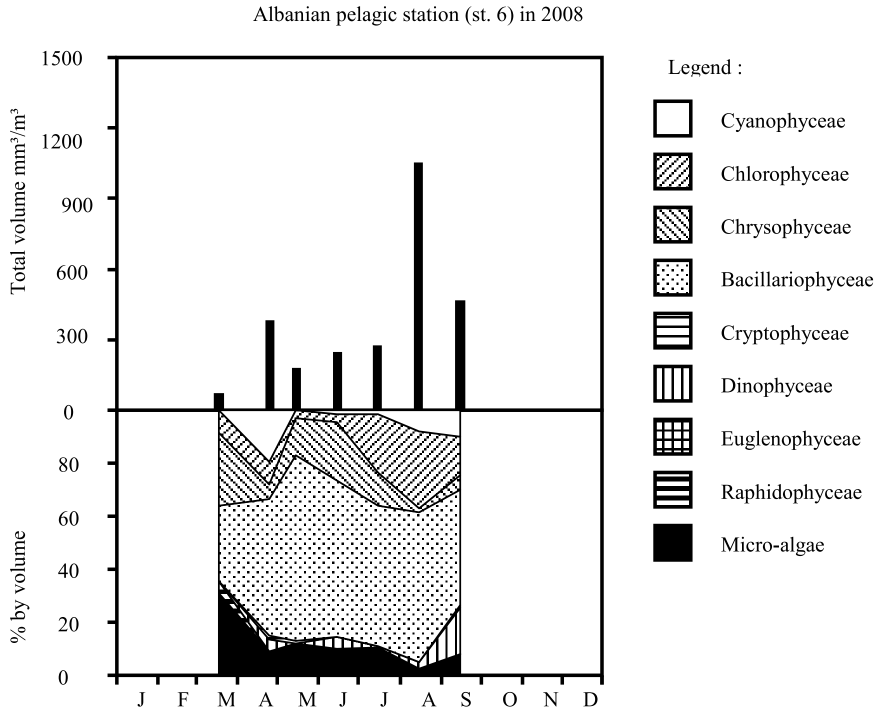

Fig.7. Phytoplankton assessed by volume at the Albanian pelagic station (St. 6) in Lake Skadar in 2008.

sion was confirmed by relatively high concentrations of TP and elevated counts of fecal coliform bacteria (2 300/100 ml at the 90th percentile) observed during summer, when water flow, and thus also dilution of the contamination, was low (Fig. 3c).

SPM concentrations were relatively low (average 4.5 mg/l) in the Crnojevića River, whereas nutrient concentrations were higher than in the Morača River, with levels of TP and TN varying from 6 to 222 μg/l and 310 to 1,240 μg/l, respectively. The highest nutrient concentrations were found during low flows, suggesting that sewage was an important contributor of nutrients, as also indicated by fecal coliform counts (2 400/100 ml at the 90th percentile).

Nutrient concentrations were lower in the outflow river, the Buna/Bojana, than in the tributaries, which is evidence of retention in the lake. In the Buna/Bojana, the TP concentrations varied between 8 and 19 μg/l, whereas TN levels ranged from 200 to 730 μg/l. Also, the fecal coliform bacteria count was 60/100 ml at the 90th percentile, and SPM levels were very low, usually below the detection limit.

Nutrient and sediment budget

A nutrient budget for Lake Skadar in 2008 was constructed (Table 3), assuming that most of the nutrients and sediments enter the lake through the two tributaries. Total inputs to the lake from the tributaries were calculated to approximately 176 tons of TP, 3 360 tons of TN and 77 tons of SPM. For most of the year, the loads from the Crnojevića River were considerably lower than those from the Morača, although the loads from these two rivers were nearly equal during summertime. Comparison of these results with the data on outflow in the Buna/Bojana River clearly indicates that almost all sediment inputs were retained in the lake, as well as about 50% of TP and 25% of TN.

Compared to 2008, the loads delivered to the lake from the two tributaries in 2009 were lower, despite higher water discharges. Total loads in 2009 were calculated to about 70 tons of TP and 2 500 tons of TN, which represent reductions of approximately 50% and 20%, respectively, since 2008. The reason for this decrease is not known, although it might have been related to sampling frequency, because fewer samples were collected during flood events in 2009.

Lake water quality

At the monitoring stations in Lake Skadar in 2007-2009, oxygen levels at a depth of 2 m varied from 10 mg/l in spring and autumn to around 7-8 mg/l in late summer, which agrees with findings reported by Rakocevic-Nedovic and Hollert (2005). Water temperatures in the lake varied from about 20°C in spring and autumn to 25-29°C in midsummer. In addition, the conductivity was approximately 210-240 µS and the pH was around 8, and these values are similar to levels observed in the rivers.

Water transparency in the lake varied from 1.5 to 3.3 m, with the lowest values of < 1.5 m in late summer (July-September) at the Montenegrin stations closest to the shore (St. 3 in 2007, and St. 4 in 2007 and 2008). Relatively low water visibility in the lake occurred in spring due to high riverine sediment loads, and later in summer, concomitantly with high chlorophyll a levels. During the three-year period, there was a slight decrease in the average water transparency on the Montenegrin side, from about 2.5 in 2007 to approximately 2.0 in 2009.

In general, TP levels in the lake varied between 5 and 15 µg/l, but were higher at Station 4 in Montenegro in 2008 (Fig. 4), and TN concentrations ranged from 200 to 600 µg/l and were also highest at Station 4 (Fig. 5). An exception to this general picture was noted at Station 6 in Albania, where levels of TP, TN, and chlorophyll a were relatively high in March 2008, probably as the result of the substantial loads of these substances in the Morača River in January and February.

On the Montenegrin side of the lake, the average concentration of chlorophyll a during the period April-October was 4 µg/l in 2007 (at all three stations) (Fig. 6a), 13 µg/l in 2008 (St. 4), and 4 µg/l in 2009 (all three stations) (Fig. 6b). At the pelagic Station 6 in Albania, the average concentration was 1.7 µg/l during the growing season (April-September) in 2008. In only one case did the chlorophyll a level exceed 10 µg/l, namely, a value >30 µg/l was measured at Station 4 in August 2008. This coincided with the elevated phosphorus concentrations at this station the same year, which might be explained by an intercorrelation between TP and chlorophyll a, nutrient inputs from the shore, or resuspension of phosphorus-rich sediments from the bottom due to wave action. Such resuspension seems likely, because the water levels in the lake were relatively low in late summer 2008.

In samples from the pelagic station in Albania, analysis of phytoplankton biomass showed that Bacillariophyceae (diatoms) constituted the predominant group at that site during the entire growing season in 2008 (Fig. 7). The most abundant species identified were *Cyclotella* spp. and *Fragilaria ulna*, which are known to be common in mesotrophic to slightly eutrophic lakes. Smaller amounts of some phytoplankton species that are indicators of eutrophic waters were also found, for example, *Aulacoseira granulata (+ v. angustissima)*, *A. ambigua* and *A. italica* v. *tenuissima*, *as* well as the diatoms *Nitzschia acicularis* and *Stephanodiscus hantzschii*. Some Cyanophyceae were also occasionally detected, such as *Planktothrix cf.mougeotii* and *Planktolyngbya subtilis*. In general, the Chlorophyceae did not predominate, although large volumes of members of this class were registered in August; of these, Chlorophyceae species such as *Crucigeniella pulchra, Oocystis lacustris, Pediastrum sp., Scenedesmus opoliensis* and *S. quadricauda* are common in eutrophic waters.

The maximum phytoplankton volume in August 2008 was >1 000 mm^3/m^3 wet weight, whereas the average during the growing season (April-September) was 428 mm^3/m^3 wet weight, indicating that conditions were mesotrophic. However, the actual phytoplankton biovolume might have been somewhat higher than these estimates, because, as already mentioned, some species were partly damaged during transport to Norway.

Based on the analyses of nutrient levels and phytoplankton, we conclude that Lake Skadar is in a mesotrophic state.

Information from stakeholders

In the interviews with stakeholders, 76% of the respondents stated that they regarded water quality is an important asset of Lake Skadar. They assumed that pollution of the lake would increase along with population and economic growth, and that deterioration of water quality would have potential impacts on the local economy. The interviews with people who had travelled to the region revealed that about two-thirds of them visited the lake because of its scenic beauty. Furthermore, 65% of those individuals indicated that they would be less likely to continue visiting the lake if the water quality deteriorated.

The participants in the transboundary workshop expressed the need for improved managerial and scientific cooperation between the two countries. Mitigation measures such as upgraded sewage and wastewater treatment and solid waste management facilities were recommended, as was joint monitoring of the lake and enhanced data availability. Furthermore, it was suggested that farmers be given better advice on the use of fertilizers and pesticides. However, lack of funding was considered an important constraint, and hence it was interesting that 77% of the questionnaire respondents supported the introduction of an eco-tax on tourism. The workshop participants also implied that there should be campaigns to increase environmental awareness, and, notably, about 50% of the survey respondents felt that the local communities should participate in the planning of such strategies.

The stakeholder workshops, interviews with management officials, and literature surveys considered in the present study have resulted in the following list of future development plans that could affect the nutrient levels and trophic status of Lake Skadar:

- Intensification of the agricultural sector in both Montenegro and Albania, which can lead to more extensive use of fertilizers and increased soil erosion, and in turn a rise in nutrient loads to the lake.

- Increased expansion of tourism along the coast, which can result in a larger number of visitors to the lake and its national park. This could also entail the establishment of new restaurants and hotels along the lakeshore, where there is already a lack of sewage treatment systems.

- Use of the Montenegrin part of Lake Skadar as a source of drinking water for the areas of the coast that are more widely affected by tourism. The plan is to collect raw water from the groundwater wells at the bottom of the lake.

- Hydropower development of the Morača Valley in Montenegro and the Drin River in Albania, which can change the hydrology of the lake (COWI, 2009; Anergij Ashta, 2010).

- Dredging of the Buna/Bojana River to reduce flooding problems, which might increase the throughflow of the lake, lower the water levels, and decrease the area of wetlands along the lake.

DISCUSSION

In 2008, the nutrient loads delivered to Lake Skadar from the two monitored tributaries amounted to 176 tons of TP and 3 200 tons of TN, and the area-specific loads in the Morača and Crnojevića Rivers were 50-70 kg/km^2 of TP and 950-1 100 kg/km^2 of TN.

By comparison, rivers flowing to the Baltic Sea have been reported to have area-specific loads varying from 11 to 42 kg TP/km^2 and 204 to 1 220 kg TN/km^2 (Stålnacke et al., 1999), and the highest loads were found in Danish streams that were heavily affected by agricultural runoff. Eight of the main load-bearing rivers in Norway had in 2008 area-specific loads of 3-13 kg TP/km^2 and 72-380 kg TN/km^2, whereas the Orre River, which is strongly influenced by agriculture, had an area-specific TP load of 45 kg/ km^2 (Stålnacke et al., 1999). Considerable concern has been expressed about the Orre River, which has resulted in government funding for monitoring, river-basin management plans and implementation of measures to reduce the nutrient inputs.

Despite these high nutrient loads, data on chlorophyll a concentrations and phytoplankton biomass from the present survey indicate that Lake Skadar is mesotrophic. Rakocevic-Nedovic and Hollert (2005) performed phytoplankton counts on the Montenegrin side of the lake in 2003 and 2004, and their results suggested mesotrophic conditions, although relatively low species diversity implied increasing eutrophication. Earlier, in 1998-1999, phytoplankton analyses performed by Rakaj et al. (2000) on the Albanian side of Lake Skadar indicated oligotrophic conditions. Further studies are needed to ascertain whether the mentioned observations are evidence that the lake is slowly becoming more eutrophic. In short, it is important to ensure more systematic monitoring of the lake, preferably employing similar sampling dates, frequencies and parameters on both sides of the border.

An important factor contributing to the current mesotrophic state of Lake Skadar is believed to be the large volume and low residence time (100 days), which can reduce the degree of eutrophication despite high nutrient loads (Dillon, 1975; Janus and Vollenweider 1984). In addition, part of the inflow to Lake Skadar is derived from groundwater emerging at the bottom of the lake. Accordingly, the plans to use this groundwater as a source of drinking water along the coast may have an impact on the trophic status of the lake. It has been shown that extraction of water for irrigation purposes increased the risk of eutrophication in Lake Macro Prespa, which is another large lake in the Western Balkans (Matzinger et al., 2006).

There are additional development plans in this region that can potentially change the hydrology of Lake Skadar, including hydropower and dredging activities. In addition, climate change is expected have an effect on water level fluctuations in Mediterranean lakes if the summers get dryer (Coops et al. 2003), and concentrations of phosphorus in shallow Mediterranean lake systems have been shown to increase in dry years (Özen et al., 2010). This agrees with data on Lake Skadar since phosphorus levels were higher and water levels lower in 2008 than in 2009.

Nutrient and chlorophyll a levels were highest on the Montenegrin side, where the main tributaries enter the lake, and therefore abatement measures to reduce nutrient inputs would likely have the best effect if focused on that part of Lake Skadar. Analyses of tributary water showed that there was a low correlation between TP and suspended sediments. That finding, in combination with high nutrient and fecal bacteria concentrations during low flows, suggests that untreated sewage may be an important source of nutrients to the lake. According to Kaukelaar et al. (2006), the sewage treatment plant that serves the Montenegrin capital Podgorica was designed to handle only about 50% of the actual needs in 2005. In addition, stakeholders interviewed in the present study reported that there was insufficient treatment of the sewage from the former capital city of Cetinje, which lies in the catchment area of the Crnojevića River. Consequently, improvement of existing sewage treatment plants and the construction of new facilities, especially in the larger cities, should be prioritized, and the first steps towards achieving such goals are in fact already underway (http://www.pro-con.me/eng/projects.php?ak=t&p=2). In addition, if tourism at Lake Skadar increases, it will be necessary to ensure that there is adequate sewage treatment for restaurants and hotels along the lakeshore, perhaps including stand-alone systems. Furthermore, if agriculture is intensified, farmers will need more advice on the proper use of fertilizers.

Overall, it is very important to monitor the effects of both abatement measures and new pressures on Lake Skadar and its catchment area. Timmerman and Langaas (2004, 2005) have emphasized that access to relevant and reliable data and information is vital for the successful management of transboundary catchments. However, the present study and other investigations conducted in this region (Keukelaar et al., 2006; Skarbøvik et al., 2010) have demonstrated that data availability and reliability can be a major challenge.

Conclusion

Lake Skadar can be described as both a unique and a typical lake. Its uniqueness is reflected by its large size and its immense biodiversity, including several rare and endemic species. Its typicality is linked to the water management challenges in the region, because rapid societal and economic development can have a considerable impact on water bodies, and the availability and reliability of data can be an issue of concern.

The transboundary monitoring performed in the present study indicated that Lake Skadar was mesotrophic in 2007-2009. However, there were substantial nutrient inputs to the lake during that period, and it is assumed that the relatively short water residence time and large volume of the lake are important factors that prevent further eutrophication. Nevertheless, there are several development plans that pose a potential threat to Lake Skadar, as well as other water bodies in this region, and thus there is a need to implement mitigation measures together with improved water monitoring. The aspect of transparency and exchange of data across borders is equally important. Research on other lakes has shown that the process of recovery is often slower than the process of deterioration (Nõges et al., 2008). This is exemplified by a study showing that eight years of decreased external loading of nutrients had little effect on the trophic status of a shallow lake in Greece (Kagalou et al., 2008). Thus, it is apparent that caution should be observed in regions where the desire for economic growth can threaten water bodies that have not yet been extensively influenced by human activities.

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