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The Spatial and Temporal Variability of Limnological Properties of Bovilla Reservoir (Albania)

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Abstract A limnological survey of a man-made reservoir in the central part of Albania was conducted from May 2006 to May 2008. This water body is being constructed 15 years ago for water supply of the Tirana, capital city of Albania. The physical and chemical quality of water in this reservoir was determined and compared against universally accepted water quality standards. Water quality parameters relevant to the study area are discussed considering the ecosystem function and interrelationship among physical and chemical parameters with the biological ones. The water quality of traditional and modern reservoir was not significantly different except for a bed odour that occurs throughout of the summer. Due to the reservoirs life the eutrophication in the nowadays is not a major problem in the reservoir, but due to an intensive sedimentation rate it is predicted that will seriously affect the water body in the near future. Management strategies to improve the water use efficiency with particular reference to eutrophication are proposed. On the other hand it is recommended that an integrated approach following the IRBM criteria will be the best way of management and administration.

Keywords Limnological survey · Reservoir · Water quality · Eutrophication · Sedimentation · Tirana

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1 Introduction

Among the other problems in current limnology study, the accelerated eutrophication of lakes and reservoirs appeared to be one of the most significant (Edmondson 1991). Being located along urban and rural settlements from one side, on the other hand constantly growing human influence, particularly since the beginning of the twentieth century, has led to the introduction and even increasing of the nutrient (Krebs 1994; Wetzel 1983). Undoubtedly there are numerous studies that indicate the direct role of nitrogen and phosphorous in water eutrophication, whose presence from one side bring the biocenoses changes (Maier 1998) and from the other causes increase of production rate, primarily phytoplankton and zooplankton (Clarke et al. 1997; Hutchinson 1967).

The above mentioned problems are strongly expressed in the situation when the water bodies are used as a reservoir for water supply (Scharf 1999). It is worth mentioning that in situation of the absence of primary treatment of the water and other domestic and agriculture run-off in the catchments of concerns, the sequences of enrichment are serious. This is a case in Bovilla Reservoir. According to Krebs (1994) this situation leads to massive development of algae and succession in the phytoplankton, phenomena that are primarily reflected in suppression of the up to then dominant diatoms and green algae and frequently pronounced dominance of cyanobacteria.

The close relationship among ecological and biological factors and nutrient loads in reservoirs and their watershed are documented by a large and diverse literature (Poschlod et al. 2005; Siwek et al. 2008). Many studies are focused on the role of nutrients on primary and secondary production, including phytoplankton and zooplankton of an aquatic system (Carlson 1997; Dodds et al. 2002). Reservoir water quality and productivity are to a large extent controlled by the quantity and quality of external nutrient loading.

Various methods based on measuring of several water quality parameters (DO, turbidity, transparency, TSS, total nitrogen (N)/total phosphorous (P) ratio, chlorophyll *a* (chl *a*) concentration, and transparency) are used as independent variables to determine relationships between them and to define the trophic state of an aquatic ecosystem. The integrated approach through interrelated analyses among physical and chemical parameters with biological was revealed too. This limnological study was conducted in order to determine the reservoir ecosystem functioning.

2 Materials and Methods

Hydrographical and temperature data were obtained from the nearest meteorological station near to the Bovilla reservoir. A number of water quality parameters measured from bimonthly water samples collected during May 2006–May 2008 were evaluated to determine whether a relationship between different abiotic and biotic indicators of the watershed and water reservoir, existed. There have been analyzed for following environmental indicators that directly influence to the water quality.

pH, conductivity, Secchi disk and turbulence were obtained "in-field" using Multi-Parameter Meter HACH 54650-18. Parameters measured in laboratory were: dissolved oxygen (DO), alkalinity, UV-A, total suspended solids (TSS), total nitrogen, total phosphorous, chlorophylls contents and phyto- and zoo-plankton. The water samples were collected using width and depth integrating techniques, respectively in three stations (s1, s2, s3), at the depth profiles (1, 3, 5, 10, 15, 20, 30, 40 m) using a Ruttner bottle (Hydrobios) with a frequency of 2 months. A known volume of water (2.5 l) has been filtered directly in the field using a vacuum pump through Whatman GF/C glass-fibre filters (0.45 μm pore size) for the measurement of pigments. Filters were frozen (−20°C) until extraction with acetone. Additionally 1 l of water sample was taken for other analysis. Water samples has been stored at −20°C or preserved with sulphuric acid till pH ≤ 1 according storage protocols (Henriksen 1969; Gardolinski et al. 2001).

For the determination of nutrients, UV-A, TOC and chlorophylls a spectrophotometer Shimadzu, model UV–VIS 2401 was used, while for the determination of total phosphorus was used spectrophotometer UV–VIS Pye-UNICAM SP-5 (measurement at 880 nm). Chemical parameters were determined according to APHA (1988), BMZ (1995) and EC Directive (1975) standard methods for water analysis.

The samples for the qualitative analyses of phyto- and zoo-plankton were collected with plankton net Nanzen 20, that was also used for the filtration purposes. The samples have been preserved in 4% formalin (Haney and Hall 1972). Biological data obtained, covered qualitatively and quantitatively the zooplankton with an assessment of the trophic state using the standard Pantle–Buck and Carlson method (Pantle and Buck 1955; Carlson 1997) based on the qualitative and relative quantitative composition of *Rotifera*, *Cladocera* and *Copepoda* species.

In the course of three years, several field trips were undertaken in order to estimate the plant cover vegetation, texture of the active soil layer, habitat health and degree of erosion in the watershed. The role of the different indicators of the ecosystem health of Bovilla watershed were modelled by a scale values beginning from 1 point (worst), up to the 3 point. For example, high rate of the rainfall in the watershed was evaluated with 3 point (the best), that show good condition for naturally growing of plants. The present conservation status were evaluated according to the methodology of EEA (2007) for Habitats of European interest and illustrated under three "traffic light" categories ("favourable"—green; "unfavourable inadequate"—amber; "unfavourable bad"—red; unknown; EEA 2007).

3 Results and Discussion

3.1 Watershed Description

Bovilla reservoir is situated in East Northern side of the Tirana town, and 15 km north of it. It has a surface area of 4.575 km^2 (Fig. 1). The watershed covers an area of approximately 90.97 km^2 and rises sharply from the surrounding reservoir and is divided by several tributaries, running in a general east–west direction. The climate of the watershed is Mediterranean of sub-hilly character with cool wet winters and hot dry summers.

Geologically, the substrate formations originate from Triassic and Cretaceous age according to Kabo (1991). It belong mainly to flyshes (clay, sandy rock, alevrolythes),

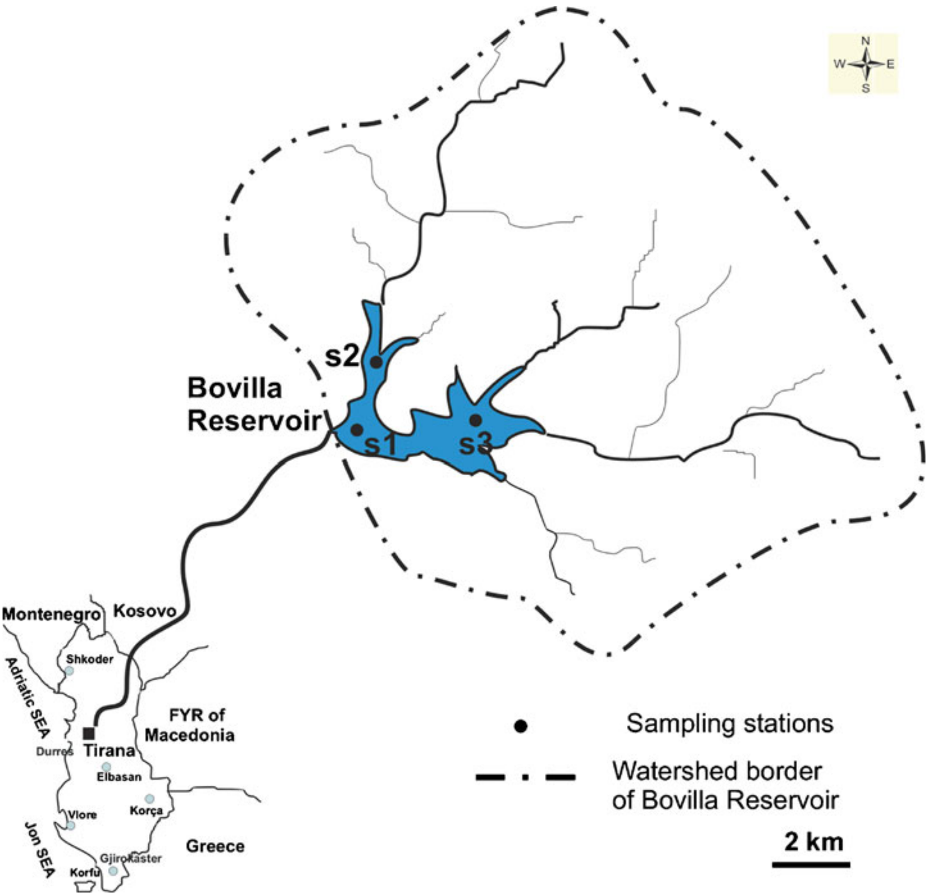

Fig. 1 Location of Bovilla watershed and sampling station (s1, s2 and s3) on its reservoir

which are very erosive and that extends in north and eastern slopes of the watershed. The rock formation observed in the area are the limestone of upper Cretaceous, belonging to the mountain chain Kruja–Dajti and more resistant to erosion. These formation constitute the medium to high relieves, while the flyshes formed the hilly relieves, where from the geomorphological point of view, the relief of the watershed is mainly hilly-mountainous (the last ones mainly in periphery), with powerful slopes processes. Erosive formations, woodcutting and denuding from the vegetation, and intense rainfall have influenced and strengthened clayey torrents, erosion spots, erosion of slopes, and landslides, that end and fill continuously the Bovilla reservoir. It is quite evident that the lowest slopes, up to 700–800 m, are eroded, mainly during winter time. It has also helped by unstable clayey texture of hills soil. The lowest slopes are also the most exploited from the agricultural farms of the inhabitants; hence, there are observed degradation of vegetation, i.e. that of mixed oaks, of some pastures, forests and Mediterranean shrubs.

3.2 The role of physical and chemical parameters on quality of Bovilla drinking water

Drinking water lakes shows variable values of chemical parameters, that we adjudged is related to the geomorphology of watershed, lack of stratification, sedimentation, occurrence of phyto- and zoo-plankton in the water etc (Baykal et al. 2000; Morkoç et al. 1998). Also, investigated annual rainfall, turbidity, pH, DO, transparency, nutrients, chlorophyll contents (Chl *a*) and trophic state index (TSI) bimonthly variation are shown as Figs. 2, 3, 4 and 5 respectively.

The Table 1 show high content of suspended solids, particularly during the winter time that several times exceeded 25 mg L^{-1}, that is the EU Directive 75/440, 1975 (EC 1975) for raw drinking water quality standard required for surface waters intended for the abstraction of drinking water (EC 1975). However, the results show normal values of pH and relatively high values of turbidity and a low transparency (2.5–3 m) of the water (Table 1), equal to category A_2, This was especially during the rainfall seasons, with a high rate of erosion in the watershed and relatively high concentrations of nitrates. It is evident in Fig. 2 that the water quality worsened during

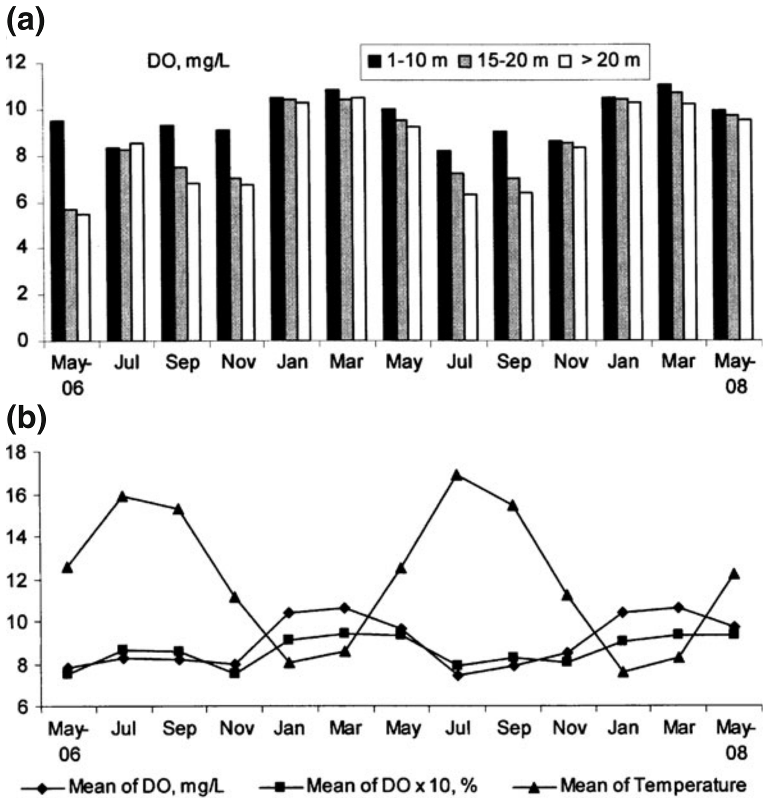

Fig. 2 **a** Dissolved oxygen (DO) profiles at different layers of Bovilla reservoir **b** Variation of DO (shown as mean % saturation or mg L^{-1}) and mean temperature (°C) on the all water column of station one (s1) from May 2006 to May 2008

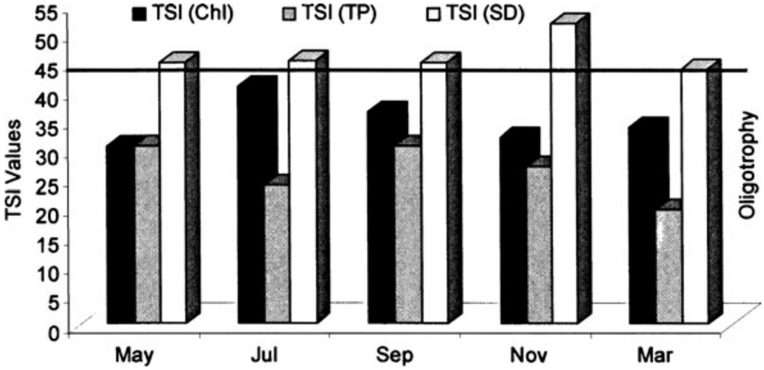

Fig. 3 Bimonthly TSI values of SD, chlorophylls (Chl) and total phosphorus (TP) in Bovilla reservoir during May 2006 to March 2008

the period of stratification (May to September), such as the dissolved oxygen in the hypolimnon (categories A_2 and A_3). This principally is the main factor contributing to the high values of Secchi disk transparency and the relatively low values of trophic state for chlorophylls and phosphates (Fig. 3). We classify this group as belonging to mesotrophic state based on the values of TSI (SD) and oligotrophic for TSI chlorophylls (Chl) and TSI total phosphorus (TP; Carlson 1997).

In-addition, the highest mean values of nitrogen was observed in May and has a value of 0.278 mg L^{-1} and minimum in November with a value of 0.149 mg L^{-1}. Concentrations of N-NO_3^- observed in depth from 1–15 m were lower (0.16 mg L^{-1}) and increased in depth more than 15 m (0.25 mg L^{-1}). The obtained data, indicates two significant correlations with pH ($R^2 = 0.823$; $n = 13$) and conductivity ($R^2 = 0.795$; $n = 13$) and a negative linear correlation with phytoplankton (cells/ml; Fig. 4). The high concentrations of nitrogen in depth of Bovilla water is influenced by release of nitrates under aerobic conditions due to relatively high values of DO in the water column (Fig. 2) and high volume of discharged water from Bovilla reservoir

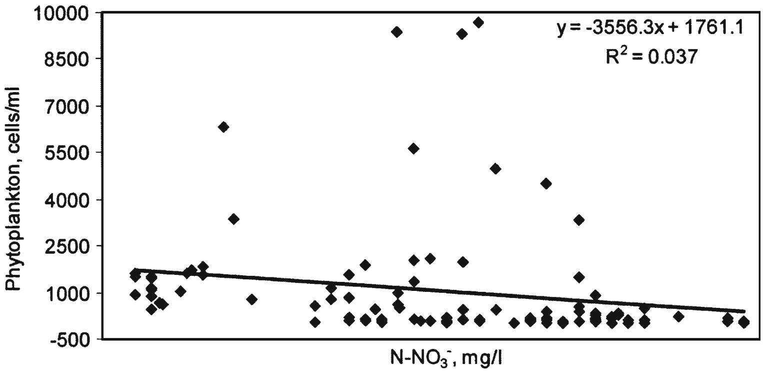

Fig. 4 Linear correlation between N-NO_3^- and Phytoplankton (cells/ml) in Bovilla water, during May 06–May 08, where: *x* N-NO_3^-; *y* phytoplankton, cells/ml; *R* correlation coefficient; $P = 0.05$

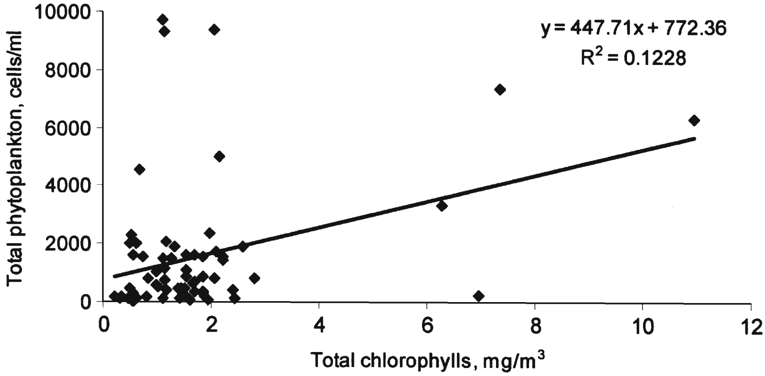

Fig. 5 Linear correlation between total chlorophylls (mg/m^3) and phytoplankton (cells/ml) in Bovilla water, during May 06–May 08, where: *x* total chlorophylls; *y* phytoplankton, cells/ml; *R* correlation coefficient; $P = 0.01$

(1800 l/s). Low concentration of N-NO_3^-in the upper part of water column is linked with high growth rate of phytoplankton in epilimnion.

Phosphorous concentration in water is essential due to its role as limiting factor of the biological productivity of the water ecosystems, particularly of chlorophyll-*a*. From the above, it is obvious that the data are in good correlation with other data obtained for the reservoirs (Haggard et al. 1999; de Medina et al. 2003; Higgins 2006), and quite different for some others eutrophic reservoirs or lakes (Porcalová 2006; Mijović et al. 2006; Shuka et al. 2005). Nitrogen and phosphorus were generally low in the whole water column; total phosphorus was with few exceptions below 10 μg L^{-1} P-PO_4, (May, 10.9 μg L^{-1}), when relatively high values were observed especially in the thermocline (see Table 1). A decrease of nutrient concentration was observed on March with 4.05 μg L^{-1} (P-PO_4), and on September–November with the lowest concentration of nitrogen (0.149 mg L^{-1}). The results show a linear correlation between P-PO_4^{3-} and phytoplankton ($y = 55.528x + 738.93$; $R^2 = 0.044$) with a confidence level 0.05. Apparently there is linear correlation in ratio TN/TP and growth and non-growth season (Table 1). All the data shows that phosphorous is limiting factor of the biological productivity of phytoplankton and zooplankton in Bovilla reservoir. The high percentage of Ca^{2+} observed in Bovilla water (34 to 40 mg L^{-1}), cause

Table 1 Bimonthly means values of some physical and chemical water parameters in Bovilla, during May, 2006–March, 2008

Physico-chemical parameters	May	Jul.	Sep.	Nov.	Jan.	March
Rainfall (mm)	215	126.5	141	472	548	382
Turbidity (NTU)	1.2	2.6	2.19	8.65	7.66	3.4
Transparency (m)	2.55	2.6	2.9	2.1	2.05	3.1
Conductivity (μS/cm)	307.6	301.8	296.5	296.44	309.27	324.3
P-PO_4^{3-} (μg L^{-1})	10.9	4.7	6.46	5.01	4.51	4.05
N-Total (mg L^{-1})	0.278	0.206	0.168	0.149	0.263	0.215
TN/TP	25.5	43.83	26	29.74	58.31	53.1
Chl *a*(mg/L; epilimnion)	1.45	1.96	4.02	1.56	1.78	1.45
Chlorophyll content (mg/L)	1.36	1.63	2.675	1.12	1.66	1.31

the sedimentation of phosphorous in forms of $Ca_{10}(PO_4)_6(OH)_2$. The absence of anaerobic conditions in depth, prevent the release of P-PO_4^{3-}across the sediments to the water. This means that the source of phosphorous in the Bovilla water is from the watershed.

Lakes and reservoirs with a phosphorus concentration less than 20 μg L^{-1} are generally free of negative effects; higher concentrations are accompanied by increasing of negative effects. Also, from Figs. 4 and 5, the variation of chlorophylls (epilimnion) with phytoplankton cells in water of Bovilla Reservoir is depicted. From the Table 1, it is evident that the lower values of nutrients and conductivity in Bovilla reservoir are in close relationship with low cover vegetation on the watershed, comparing with that of forested areas. Despite the high rate of precipitation and taking into cognizance the absence of conservation measures (red, traffic light), we noted that the indicators point to the fact that area have lost active layer of soil over time.

In general, the water quality of Bovilla reservoir comply well with the norms of class A1 of drinking water quality standards of EC Directive 440 16/6/1975 (EC 1975) for physic-chemical parameters: pH, conductivity and nutrients (nitrogen and phosphorous; Table 1) and class A2 for few TSI (SD) samples (see Fig. 3).

Bovilla reservoir profiles, from the limnological point of view, are characterized by deep reservoir similar to a classical lake. Vertical thermal stratification was observed from late spring up to early fall and only one overturn is developed beginning from late fall up to early spring (fully developed on January). However stratification process and relative changes of chemical and biological parameters appear more weakly because the high water volume which flows into the treatment plant. Bovilla reservoir is a warm monomictic water body like other fresh water ecosystems (Wetzel 2001) that never freezes and stratifies with high stability during the summer season. The epilimnion extends from 0 to 10 m of depth, the thermocline is located between 10 to 15 m and the water in the hypolimnion below 15 m is nearly isothermic.

3.3 Biological Indicators of Bovilla Water

The growth of phytoplankton in Bovilla reservoir was relatively high during spring to autumn, with an evident peak, up to 2,794.53 cells/ml in May (Fig. 5). The maximum density corresponded with beginning of the stable thermal stratification of the lake. The highest growth was observed in the upper layers (epilimnion; 1–10 m). The lowest values were observed during winter (November–January), period of the year when the temperature was the same throughout the water column, close to the environment temperature.

Nevertheless, phytoplankton biomass was generally low, which is characteristic for oligotrophic waters of the first quality, but with a tendency to the mesotrophic state (second quality), during the maximum phytoplankton growth in spring (May; see Fig. 5). The related positions of the maximum phytoplankton growth in epilimnion and hypolimnion are enclosed. We observed that due to a characteristic seasonal pattern of limnetic biota, the coherence between respective pairs of the reservoir was stronger when we analyse the correlation effects. Thus, in order to comment generally on the changes in zooplankton community, it is necessary to consider the changes in phytoplankton community. A complete scenario of the distribution of the planktons are shown in Fig. 6. Daphnia and Diaphanosoma dominated the cladoceran community in the reservoirs with large transparency values (more oligotrophic),

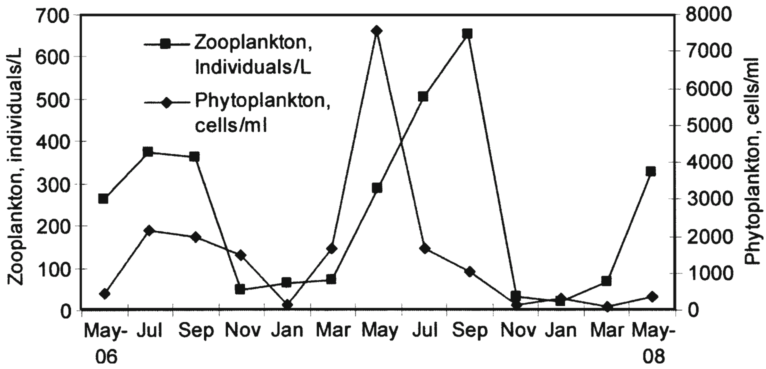

Fig. 6 The time course of average in the whole water column of phytoplankton (cells/ml) and of zooplankton (individuals/L) in Bovilla from May 2006 to May 2008

while Bosmina dominated in other type of reservoirs (Caramujo and Boavida 2000). In our case there is a clear presence of *Bosmnina longirostris* that is in discordance with TSI values. We thought that a proper interpretation should take into consideration the presence of carnivore cyclopoida species.

An important component of the Bovilla reservoir is the presence of *Cyclops vicinus*. While some individuals of *C. vicinus* are present in the plankton throughout the year, bulk of population overwrites as diapausing copepodid larval stages IV and V on the bottom reservoir (Brandl 1998). We inferred that they become active in the plankton usually in April and quickly mature thereafter to reproduce. At this time of the year, they form main component of the zooplankton for Bovilla Reservoir. All development stages including numerous larvae are then present for about six weeks until the end of May or early June. Since the reproduction is continuous no separate cohorts can be distinguished (Rohrichova 1997). The presence of *Diaphanosoma brachiurum* and its juveniles in Bovilla Reservoir should be subject of control by the *C. vicinus* (Brandl 1998). There is a delay of spring maximum in between copepods and cladocera species. This was recognized by Brandl (1998). While the supply of algal food is high during the spring development of usually small unicellular algae, the main herbivores cladoceran *Bosmina longirostris* and *D. brachiurum* with their ability of quick growth are reflecting the difference with copepods. As a temperate water body with a typical temperate climate the seasonal changes in temperature exert an effective control as driving force. This is reflected in a type of interrelationship where all biological components have reflected a typical seasonality for Bovilla case. The biological seasonality reflected in both phytoplankton and zooplankton is in direct relation with temperature and other physical and chemical parameters oscillation (Figs. 2 and 3).

3.4 Land/Water Interaction: Availability of the Allocutions Organic Matter and Nutrients in Case of Mismanagement

The total length and thus, the direct contact between the shore line of the reservoir and watershed have its maximum in the first impoundment phase. Before bank erosion by waves and the growth of deltas in the mouths of the tributaries shorten the length of the shoreline, this contour completely corresponds to the relief of the land (Uhlman 1998). In fact this is very well reflected in the case of Bovilla Reservoir when it takes into considering two main tributaries of its feeding (Fig. 1).

As it is pointed out by Rzoska (1978) and other authors, a river system is nearly completely controlled from outside, and there is (with expectation of estuaries) no return of materials from a downstream into the upstream segment. Unlike this situation in rivers, the residence time of materials in reservoirs is long, and the transport of dissolved substances in ellipsoid or triangle-shaped reservoirs of the same type as in lake (Uhlman 1998). In that case we have a food web of the same principal structure as in lake.

As in previous studies (Dring et al. 2002), from this study, it is deduced that the watershed of Bovilla Reservoir plays an important role on its water quality since it characterised by different habitats and heterogeneous vegetation types including Mediterranean shrubs and forests, oak forests, beech forests and mountainous meadows in high elevations. Taking into consideration the Mediterranean ecoregion of the studied area, its land cover is primarily deciduous forest that hosts the largest population density on hilly and limestone substrate zones. The forest and dry grasslands are other parts of vegetation cover that determinate the water regime and level of erosion in the watershed.

Herbaceous plants dominate to the shrubs and woodland species. Life forms of the species growing in Bovilla watershed belongs to *Chameophyta* and *Therophyta* that shows degradation trend of the ecosystem, due to woodcutting, overgrazing, and fires. On the other hand, the specie composition is dominated by the plants of herbaceous and legume families, which have a good indication to the soil texture.

The ecosystem seems to be in non-equilibrium due to the increased of human impact on some part of the watershed, especially on northern and eastern slopes. So, several pioneer species like Common hawthorn (*Crataegus monogyna*), Hairy Canary clover (*Dorycnium hirsutum*), Elmleaf blackberry (*Rubus ulmifolius*), Evergreen rose (*Rosa sempervirens*), Wild pear (*Pyrus amygdaliformis*) and Western brackenfern (*Pteridium aquilinum*) are present as indicators of the degradation favoured also by clay soil texture and low level of nutrients in it (see Table 1).

Overexploitation of the forests and shrubs combined with the unmanaged grazing, are the main reason for the decrease in vegetation cover, particularly on lower slopes. It is well known that changes in land cover and land use affect ecological landscape functions and processes, which mean the erosion phenomena, are very strong; also the capacity of water retention of the eroded land is very scarce (Papastergiadou et al. 2007; Wissman 2006).

Based on our data, it was observed that damage to the vegetation cover, not only to the shrubs but also to the real forests is obvious. One of the dominant human activities seems to be the woodcutting, used mainly for industrial purposes, in Kruja and Tirana. Moreover, in the region, it is foreseen to grow up about 1100 cows, 800 horses and mules and more than 1000 domestic livestock, sheep and mostly goats. It seams that livestock and farming may cause in the near future an increase in the nutrient loads in the reservoir. Furthermore, the soil texture contributes also in reduction of the infiltration rates and the retention time such that runoff in the catchment is shortened. This contradiction is the major cause of the erosion and transport of solids by the tributaries and the sedimentation in the reservoir. From the

Table 2 Trends of key indicators that determine ecosystem health of the Bovilla watershed

Scale value	Indicators of Ecosystem Health	Conservation status (CS)
2	Soil texture (clay)	Red
1	Level of slopes degree (high)	Red
3	Annual mean values of rainfall (high)	Red
3	Annual mean values of air temperatures (normal)	Amber
3	Vegetation type (dominate Thermo-Mediterranean brushes, thickets and heath-garrigue)	Amber
2	Plant cover vegetation (graminaceae)	Red
2	Specie composition (dominate herbaceous plants)	Amber
2	Life forms of the species (dominate *Chameophyta*)	Amber
1	Habitat disturbance	Red
2	Economical community status	Red
2	Awareness of local communities	Amber

data that we acquired on the field, eleven key indicators were evaluated to estimate the conservation status and ecosystem health of the Bovilla watershed (Table 2).

A detailed analysis of the indicators (Table 2) shows good ecological and biological condition for growing plants in controversy with amber to red trends of conservation status of ecosystem health. This trend is supported mainly by the terrain condition, low local economical rate of development and mismanagement.

Nevertheless, creation of buffer zones around reservoir can be a good measure for erosion prevention and protection of drinking water quality. Based on other studies, for example Rosenmeier et al. (2002), Zhou et al. (2002) buffers protect water quality by slowing down the flow of water, thus facilitating the trapping of sediment, organic matter, nutrients and reduce the rate of water runoff and erosion. The presence of some typical species of river valleys, such as Sycamore (*Platanus* sp.) and Willows (*Salix* sp.) etc., can be considered as an important feature, considering their capacity to decrease erosion rate. Also, Cesaraccio et al. (2004) recommended for forestation of eroded and uncovered areas also the use of leguminous plants such as bushy Canary clover (*Dorycnium pentaphyllum*) and Montpellier rock-rose (*Cistus monspeliensis*) that are native species for the Mediterranean region, and growing well and in the Bovilla watershed. Some remediation measure carried out in the area some decades ago include reforesting the territory with pine-trees, mainly Aleppo pine (*Pinus halepensis*) and Black locust (*Robinia pseudoacacia*), helped combating and reducing the erosion rate, but it also led to decrease in the plant diversity and plant cover. We thus prefer that subsequent reforestation activities should include the use of native species, like Italian oak (*Quercus frainetto*), Oriental Plane tree (*Platanus orientalis*), and Willows (*Salix* sp.). These plants we envisaged would prevent erosion and decrease sedimentation rate.

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