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Limnological management of the Amadorio Reservoir (Spain) during an extremely dry summer

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Introduction

The management of reservoirs requires a compromise between the use of the water resources and the maintenance of ecosystem health. The role of limnologists in promoting balance must be of special importance, because they can give the administration guidelines regarding the correct freshwater management.

Amadorio Reservoir is a medium-sized, man-made lake located near the Mediterranean coast of eastern Spain, approximately 2 km from the sea. This reservoir is one of the main sources of water for a popular tourist area where more than one million people congregate during summer. After a 5-year drought, the availability of good-quality water did not meet the demand. A management plan was undertaken that combined the control of water quality, inputs of water, changes in the discharge fluxes, and dilution of hypolimnetic waters with others of better quality at the water treatment plant. These measures, based on limnological advice, preserved the ecosystem health and ensured an adequate supply of drinking water.

Material and methods

Study site and sampling

The limnologically based management of the Amadorio Reservoir described here was performed during the summer of 1996. At this time, the reservoir contained only 1.30×10^6 m^3, whereas the maximum capacity is 15.8×10^6 m^3.

Because of the gypsum-rich substrate of the catchment area, water is highly mineralised (1–2 mS cm^{-1}), sulphate and calcium being the most abundant ions. Due to the high sulphate concentrations, an anoxic hypolimnion with high sulfide concentrations usually develops during the summer stratification period.

Water quality was controlled at time intervals of 3–6 days from early summer to middle autumn. Sampling was done at three stations in the reservoir at several depths, and also at the sites of inflowing and outflowing water.

Water flow measurements

The main water input to the Amadorio Reservoir usually comes through the Sella River, a small stream which is usually dry during the summer season, except when occasional storms discharge water in the catchment. Water flow measurements in the main water input to the reservoir (Sella River) were performed periodically by means of a currentimeter situated in a gauging station. Other occasional inputs come from a controlled pumping flow from the Torres River. Due to the low water level, the only operative outlet was the one near the bottom and the water outflow was regulated by pumping.

Water quality analyses

A number of physico–chemical and biological parameters were monitored every 3–6 days. Vertical profiles of conductivity, dissolved oxygen, pH, Eh, and light penetration were recorded in situ at each sampling site by using the appropriate sensors. The main chemical and microbiological parameters (Table 1) were determined according to APHA–AWWA–WEF (1992). Phytoplankton was counted after sedimentation of direct samples by the Utermöhl method. Photosynthetic pigments were determined after extraction in 1:1 90% acetone/dimethyl sulfoxide (Shoaf & Lium 1976), or in vivo (to detect the presence of phycobilins of cyanobacteria) by filtering samples through GF/F glass fibre filters (Trüper & Yentsch 1967).

Several estimations of fish density were performed throughout the summer by means of an echosounder (Moreno-Amich 1990).

Results and discussion

Because of the climatic regime, natural inputs of water to the reservoir are scarce during summer. As the demand for drinking water during

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Table 1. Ranges (maximum–minimum) for parameters monitored in the Amadorio Reservoir during the period July–October, 1996.

Parameter	July–August		September–October
	Epilimnion	Hypolimnion	
O_2 (mg/L)	6.3–10.4	0–2.0	4.5–10.7
O_2 saturation (%)	80–126	0–22	52–116
Conductivity (µS/cm)	1640–1680	1678–1715	1693–2210
Temperature (°C)	24.0–28.1	17.9–24.0	17.6–23.1
pH	8.1–8.5	7.4–7.6	7.9–8.2
Secchi disk (m)	0.70–0.90	–	0.67–0.88
Alkalinity (meq/L)	1.49–2.97	2.51–3.30	1.89–3.82
Sulphate (mg/L)	385–585	395–560	310–640
Chloride (mg/L)	158–187	153–188	179–305
Calcium (mg/L)	170–192	180–194	175–240
Magnesium (mg/L)	39–55	33–50	47–73
Sodium (mg/L)	72–93	72–93	96–210
Potassium (mg/L)	2.1–3.1	2.0–3.1	4.0–5.6
Fluoride (mg/L)	0.18–0.21	0.18–0.21	0.05–0.16
Nitrate (mg/L)	1.9–4.8	0.006–0.27	0.8–1.7
Nitrite (mg/L)	0.03–0.11	0.03–0.12	0.03–0.09
Ammonia (mg/L)	0.02–0.1	0.56–0.79	0.24–0.39
Soluble reactive phosphorus (µM)	<0.03–0.1	0.033–0.083	<0.03–0.1
Soluble reactive silica (µM)	150–230	184–243	198–250
Iron (mg/L)	0.13–0.58	0.11–0.44	0.15–0.31
Manganese (mg/L)	<0.05–0.23	<0.05–0.24	0.08–0.21
BOD (mg/L O_2)	1.9–2.9	1.9–2.7	1.3–6.1
COD (mg/L O_2)	5.0–12.6	5.4–11.1	8.4–11.2
Total phosphorus (mg/L)	0.013–0.021	0.014–0.035	0.02–0.154
Phenols (mg/L)	0.02–0.24	0.02–0.31	0.003–0.033
Suspended solids (mg/L)	9.4–20.7	6.5–21.1	9.1–38.5
Particulated organic matter (mg/L)	5.1–10.8	3.1–8.4	3.8–11.1
Sulfide (mg/L)	0	0–0.30	0
Heterotrophic plate count (c.f.u./mL)	200–6700	300–2400	170–7500
Total coliforms (c.f.u./100 mL)	0–40	20–190	0–70
Fecal coliforms (c.f.u./100 mL)	0–26	10–120	0–27
Fecal streptococci (c.f.u./100 mL)	0–27	20–110	0–10
Chlorophyll *a* (µg/L)	10.5–37.8	1.8–9.8	6.1 –43.3
Bacteriochlorophyll *a* (µg/L)	0	0–2.6	0

this period increases due to tourism, a critical situation was established with low water availability and a risk to the ecosystem health.

Hydraulics

The hydraulic regime of the reservoir (inflows, outflows, rain and total volume of water) is shown in Fig. 1. From July to October, water volume in the reservoir decreased from 1.30 × 10^6 m^3 to 0.1 × 10^6 m^3. Four periods can be established according to the water outputs from the Amadorio Reservoir. From the beginning of July to middle August, outflows varied from 150 to about 250 L s^{-1}; during the second half of August they increased to 400 L s^{-1},

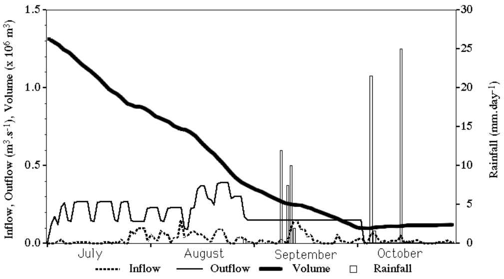

Fig. 1. Hydraulic regime of the reservoir from July to October, 1996.

decreasing in September to 150 L s^{-1}, and in October no outflows were registered. During July and August, no rain occurred whereas in September and October several storms discharged small amounts of water in the catchment area. The supply of water to the reservoir was maintained during late July and August by the exploitation of groundwater resources on the upper part of the Sella River, which allowed for the maintenance of a certain water flow into the reservoir. This was beneficial because of the increase in water resources and the changes in stratification and chemistry of the water, allowing for improved water quality. During September and October, when these groundwater resources were almost exhausted, the only inflow sources were occasional rains and water pumped from the nearby River Torres pumping station.

Vertical stratification and water quality

During summer a marked vertical stratification is usually established in this reservoir, resulting in the formation of a sulphide-rich anoxic hypolimnion which occupies the most part of the water column. In past years this was not a problem because water for domestic supply could be obtained from the epilimnion. However, during summer 1996, the water level was so low that all the water extraction points in the dam, with the exception of those close to the bottom, were inoperative. The formation of an anoxic hypolimnion resulted in a low-quality water supply for domestic use because of the accumulation of undesirable substances like ammonia, sulfide, phenol, manganese and iron. Moreover, this reduced the natural habitat for fish, promoting stress problems in the population, originally estimated to be about made up of 5000 adult individuals of golden carp.

In fact, during July 1996, water quality for domestic supply coming from the hypolimnion did not fit the quality standards (Table 1). Ammonia was the main problem, because of the formation of chloramines when the water was chlorinated. Moreover, the high concentrations of other reduced compounds increased the chlorine demand.

Because of this dangerous situation, several measures were taken to preserve the health of the ecosystem and ensure an adequate water supply. During July, after a period without water fluxes in the reservoir, vertical stratification of the water began to develop, increasing the anoxic zone with time (Fig. 2). It was obvious that the maintenance of a water flow could avoid the increase in volume of the anoxic zone, so it was decided to make use of groundwater resources to give some water to the Sella River. This water entered in the bottom part of the reservoir due to its lower temperature, promoting a progressive destratification. The velocity of this process was controlled by regulating the water fluxes in order to avoid an excessive mobilisation of nutrients, the main risk of the destratification process. This regulation limited the availability of those nutrients to the photic zone (3.9–5.2-m depth, depending on the period). The water flow was maintained throughout the warmest period in order to avoid the development of a new stratification. At the same time, hypolimnetic waters extracted for domestic use were diluted at the water treatment plant with water of higher quality from the nearby Guadalest Reservoir, decreasing the concentration of undesirable substances to levels that allowed water treatment by classical techniques. All these measures allowed for the maintenance of safe concentrations of several substances that could otherwise be dangerous for the fish population, such as free ammonia or nitrite, preserving a sufficient volume of well-oxygenated waters to ensure an adequate fish habitat.

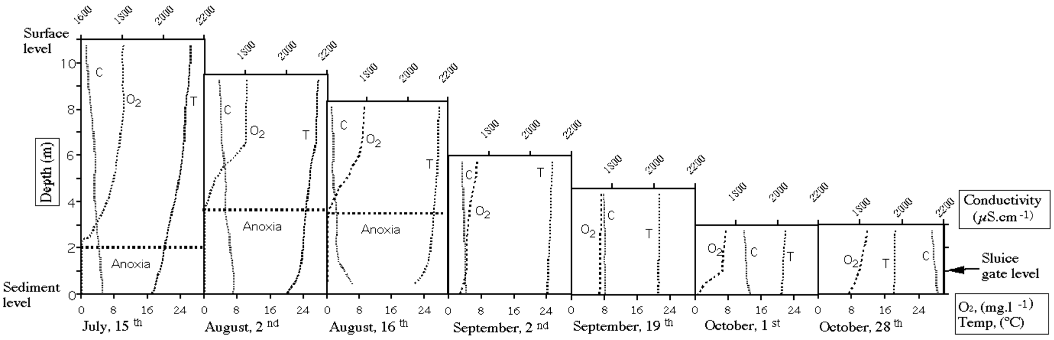

Fig. 2. Evolution of the thermal stratification, water level, dissolved oxygen, and conductivity in the Amadorio Reservoir during the period of study.

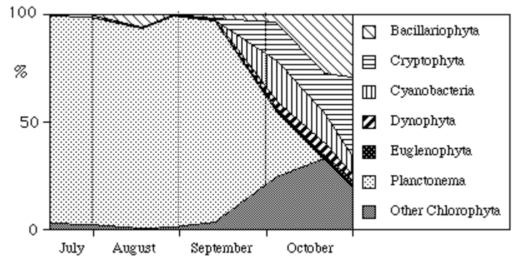

Fig. 3. Variation of the relative importance of the different algal groups in Amadorio Reservoir during the extremely dry 1996 summer.

Trophic status

The Amadorio Reservoir has usually been referred to as a mesotrophic reservoir (HERNÁNDEZ et al. 1993, DASÍ et al. 1998). During the period of this study the trophic state was at the borderline between mesotrophic and eutrophic. Inorganic nitrogen was abundant, whereas phosphorus, usually found at undetectable levels in the epilimnion, appeared as the limiting nutrient for primary producers. Chlorophyll values varied from about 10 mg m^{-3} to more than 30 mg m^{-3}, the highest values were a consequence of a nutrient enrichment of the photic zone due to the forced destratification during August. Total phosphorus and chlorophyll concentrations were significantly correlated.

During July and August, phytoplankton was dominated by the chlorophyte *Planctonema lauterbornii* (Fig. 3), a typical summer species in Mediterranean mesotrophic hardwater reservoirs (RAMÓN & MOYÀ 1984, DASÍ et al. 1998) which have a very low P content, but a high N/P ratio. Although there was a total dominance of *P. lauterbornii*, increases in the water flow during the first part of August resulted in the development of *Stephanodiscus* sp., which almost disappeared when the water flow decreased. The dominance of *P. lauterbornii* drastically declined from mid-September to its disappearance at the end of the month when the outflow was closed, temperature decreased and the nutrient content of the water rose. In other reservoirs *P. lauterbornii* is most abundant at the end of the summer and in autumn (RAMÓN & MOYÀ 1984) when the N/P ratio is very high. However, the special characteristics of summer 1996 caused the earlier fall of this alga in the Amadorio Reservoir. A more diverse phytoplanktonic population developed when the reservoir became a very shallow water body influenced by the inputs of nutrient-rich water from the River Torres and from eventual rain discharges. Then, *Scenedesmus* spp. and *Pseudanabaena* sp. developed, probably favoured by the input of nutrients, accompanied by other species expected in the autumnal assemblage in the Amadorio Reservoir such as the diatoms *Fragillaria ulna* var. *acus*, *Nitzschia palea*, and *Cyclotella ocellata* (Fig. 4).

Concluding remarks

In extreme situations of water scarcity, the

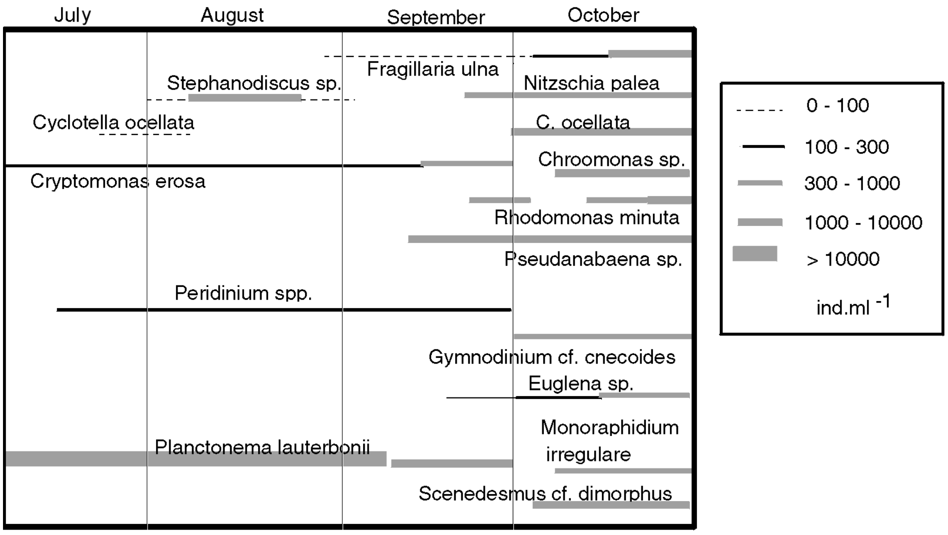

Fig. 4. Evolution of the phytoplanktonic community in Amadorio Reservoir during the extremely dry 1996 summer.

proper management of reservoirs can help to use the available water wisely as well as to maintain the ecological equilibrium in the reservoir. In the case of Amadorio Reservoir, the maintenance of an artificial flux during the dry season helped to avoid the advance of oxygen exhaustion in the vertical profile, which causes a reduction in the water quality affecting the fish habitat as well. Because natural fluxes are scarce during the summer months, the use of groundwater to ensure the water inflow to the reservoir, as well as the regulation of outflows according to limnological requirements, should be effective tools to ensure the maintenance of ecosystem health in spite of an uninterrupted use of water resources.

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