FACTORS CONTROLLING ALGAL BIOMASS IN THE COMPLEX OF WATER SUPPLY RESERVOIRS OF SEVILLE (SPAIN)

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ABSTRACT

This paper summarizes more than a decade of research on Aracena. La Minilla and El Gergal reservoirs, which belong to the water supply reservoir complex of Sevilla city (Spain). Aracena and La Minilla reservoirs were studied since July 1973 and El Gergal reservoir since October 1979. The results allowed the examination of the different factors which control thc interannual variability of the trophic state of the reservoirs.

Because of the high variability of average yearly rainfall, that is characteristic of the Mediterranean climate area, the water renewal rate of the reservoirs varies greatly from year to year. This water renewal rate plays a more important role than nutrient (nitrogen and phosphorus) availability in controlling algal biomass and consequently, primary production. Nevertheless, its relative importance depends on the phosphorus loading of each reservoir. In the case of La Minilla reservoir, water renewal rate is the only factor significantly correlated with phytoplankton biomass. In Aracena and El Gergal reservoirs both renewal rate and nutrient concentrations can account for the differences in biomass. In Aracena reservoir the highest phytoplankton biomass peaks occured in certain summers at the beginning of its history (when N/P ratio is less than 10) due to blooms of nitrogen fixing Cyanophyceae, but water renewal rate turned to be a more important controlling factor than nutrient concentration as years passed by. Although El Gergal reservoir presents the highest phosphorus input, summer blooms of Cyanophyceae do not take place, due to its natural high water renewal rate (which has even been increased by human management). The largest algal crops tend to occur during spring in El Gergal reservoir. where they reach the highest values of the 3 rcservoirs. Then, the phytoplankton biomass is maintained to similar standards during the stratification period (aproximately, 7-8 months). When phosphorus loading is extremely high, it becomes the only factor with significant importance on the control of the trophic state of a reservoir, such as in the Sau reservoir (ARMENGOL, 1988).

INTRODUCTION

Water supply to Seville city (1 million inhabitants) is supported by a complex of 5 reservoirs located in the Rivera de Huelva basin, a tributary of the Guadalquivir river. Four of them (Aracena, Zufre, La Minilla and El Gergal reservoirs) are located on the main river while the fifth (Cala reservoir) is on one of its tributaries: the Rivera de Cala (fig. 1). The Aracena reservoir was first filled in 1969, Zufre in 1988, La Minilla in 1946, El Gergal in 1979 and Cala in 1936. The main use of Aracena. Zufre, La Minilla and El Gergal reservoirs is the water supply to Seville, whereas Cala reservoir is devoted to hydroelectric production, being its outlet waters collected downstream in El Gergal reservoir. Since 1987 La Minilla reservoir has produced electricity too. La Minilla and El Gergal reservoirs allow extraction of water at 4 different depths. In the other three it is only possible to extract water from the top and from the botton of the dam.

The basin of the reservoirs consists of Silurian acid rocks and is hardly affected by human activity. The river water contains less than 250 $mg.L^{-1}$ of total dissolved solids (MARGALEF *et al*.. 1976: TOJA, 1976; ARMENGOL *et al*., 1991) but has a relatively high alcalinity (1.2-1.8 meq. L^{-1}) due to some tributaries from the calcareous zone of the Aracena Mountains (TOJA, 1976). The classification of

Aracena, La Minilla and Cala reservoirs, in relation with the whole of Spanish reservoirs has been examined in MARGALEF *et al.* (1976), RIERA & MORGUI (1990) and ARMENGOL *et al.* (1991).

From 1973, EMASESA (Seville Water Supply Company) has been carrying out a program of research on the limnological characteristics and water quality control of these reservoirs, first on Aracena and La Minilla reservoirs

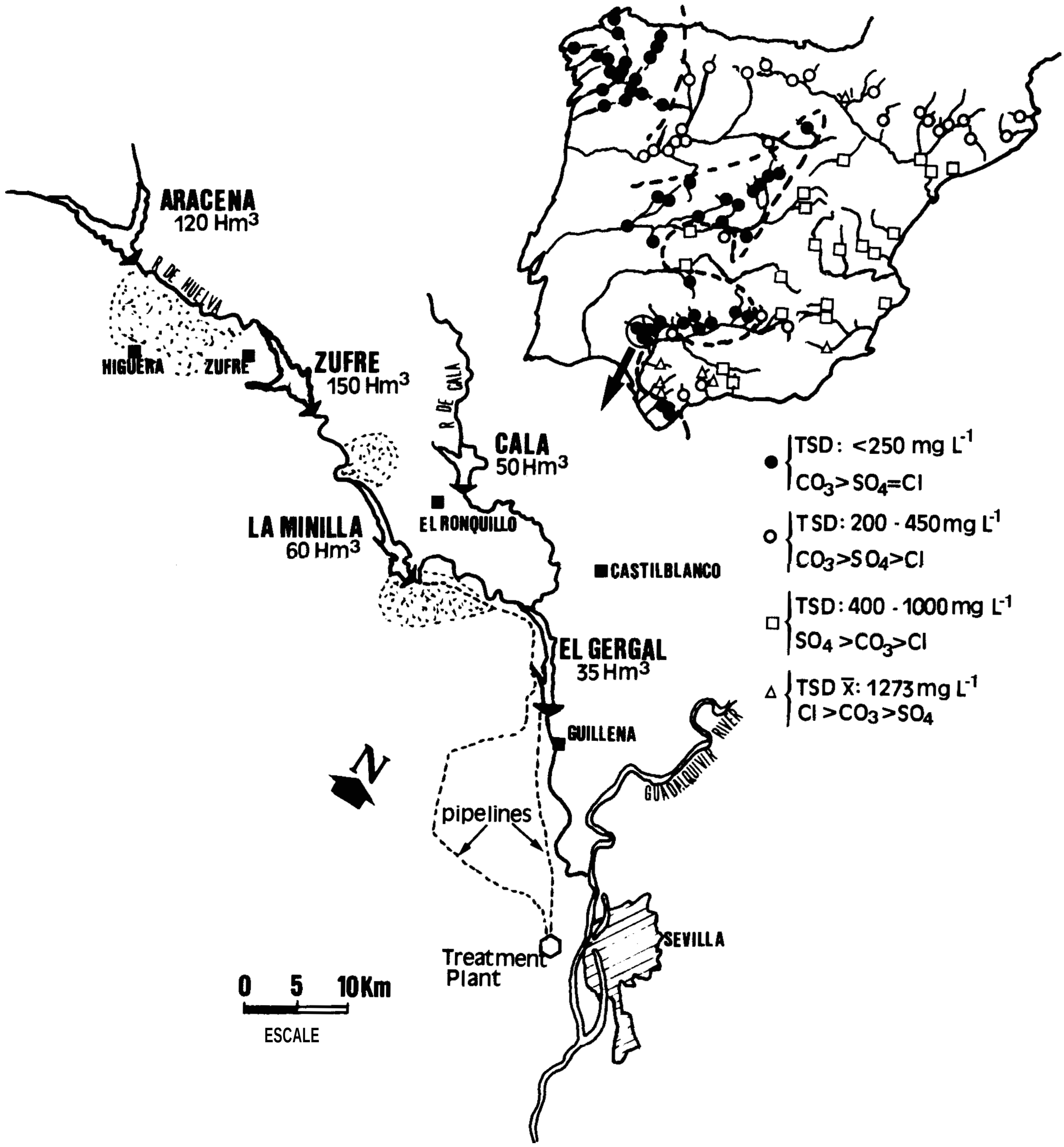

Figure 1. Sevilla water supply system and their relation to the whole of Spanish reservoirs. These was typified according to ARMENGOL *et* al., 1991. The areas with eucalyptus plantations are marked in the Rivera de Huelva basin.

and later on El Gergal and Zufre reservoirs since their first inflow. Cala reservoir has only been studied sporadically.

The results of this research have been published in papers describing aspects of the physicochemical characteristics of water (CASCO, 1990; TOJA, 1976, 1980a, 1984, 1990; TOJA *et al.*, 1981) and sediments (GABELLONE & GUISANDE, 1989), phytoplankton (CASCO, 1990; TOJA, 1976, 1980a, 1984, 1990; TOJA et al., 1981, 1983; TOJA & CASCO, 1990), periphyton (CASCO, 1990; CASCO & TOJA, 1991; TOJA & CASCO, 1990), zooplankton (TOJA, 1980b; 1983), fishes (SANCHO ROYO & GRANADO LORENCIO 1987) and management (TOJA, 1982).

In this work we will summarize the information obtained from 1973 to 1989 in Aracena, La Minilla and El Gergal reservoirs, with emphasis on the observation of the factors that control their algal crop.

MATERIAL AND METHODS

Samples were taken monthly at one sampling station in each reservoir located at 500 m from the dam. Aracena and La Minilla reservoirs were sampled from 1973 to 1989 and El Gergal reservoir from 1979 to 1989. In each reservoir samples were taken at different depths (0, 2, 5, 10 m then at every 5 m to the bottom). Nitrite was analyzed by the Shinn method (APHA 1985), nitrate by reduction to nitrite (APHA 1985), amnonia by Nessler reactive after precipitation with $ZnSO_4$ (APHA 1985) and soluble phosphorus according to Musphy and Riley 1963 (in APHA 1985). Volumes of 1-2 L of water were filtered through fiber glass (WATMAN GF/C) filters, and the photosynthetic pigments were extracted in darkness in cold methanol. The Talling and Driver formula (VOLLENWEIDER, 1969) was used to calculate chlorophyll.a concentrations. Samples of 125 ml of water were fixed with solutions of iodine in potassium iodide for later counts of phytoplankton in the inverted microscope according to the Utherm lh technique.

The water renewal rate (RR) for each month was calculated according to the formula (TOJA, 1982):

$$RR\ (\text{month}^{-1}) = \frac{\text{Volume inflow} + \text{Volume stored in reservoir}}{\text{total capacity of reservoir}}$$

This model is particularly appropiate for the Mediterranean reservoirs that have high level fluctuations both within a year and from year to year (PEREZ-MARTINEZ *et al.*, 1991). It includes both the changes of the water flow and the distance of the epilimnion to the bottom that determines the posibility of the nutrient return to the euphotic zone.

Relationships between algal biomass and limnetic conditions were described using Multiple Regression Analysis (Statgraphics Statistical Computes Program 1985). Phytoplanktonic biomass was represented by the average monthly epilimnetic (O to 10 m of depth) chlorophyll.a concentration ($\mu g.L^{-1}$). The logarithmic trasformation of the concentration of chlorophyll.a was used since primary producers respond normally to environmental factors in an exponential way. The following factors related to biomass were considered: the monthly water renewal rate (RR in $month^{-1}$), the average monthly concentrations of total inorganic nitrogen ($NO_3 + NO_2 + NH$,) (N in pg-at $N.L^{-1}$) and of soluble reactive phosphorus (P in pg-at $P.L^{-1}$) in the water column, and the ratio between both nutrients (N/P).

RESULTS

The main characteristics of the three reservoirs are shown in table 1. Inter-annual variability in all parameters is very high and is not reflected by the average values. The climatic irregularity of the Mediterranean area is reflected in the volume of water stored in the reservoirs over the years (fig. 2), especially in Aracena reservoir, which is used as a regulation dam. Although the interannual variation in La Minilla and El Gergal reservoirs is lower than in Aracena reservoir, the fluctuation within the annual cycle is much greater. Therefore, the yearly water renewal rate in the three reservoirs has been very varia-

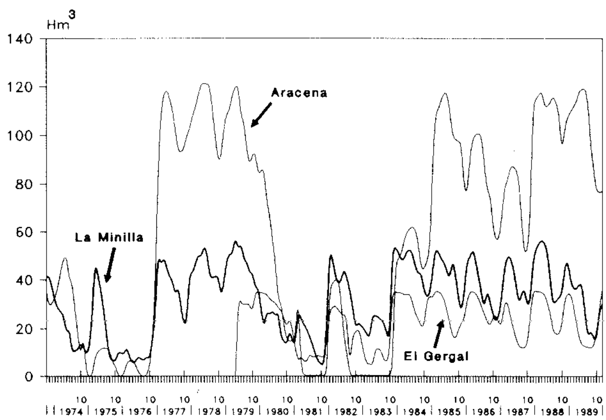

Figure 2. Evolution in time of the water volume (Hm^3) stored in each reservoir

ble, even higher than reflected in the annual average (Table 1) (Aracena between 0.18 and 2.20 yr^{-1}; La Minilla: 0.68-9.44 yr^{-1}; El Gergal: 1.10-14.85 yr^{-1}).

The level of eutrophy in Aracena and La Minilla is not very high at present, as they are located in a basin that is relatively unaffected by man. Eutrophy is higher in El Gergal due to its more recent construction and to the following circumstances. During the period 1981-83, water from the river Guadalquivir was let in, with a concentration of nitrogen and phosphorus about ten times greater than that of the river Rivera de Huelva. Moreover, this reservoir receives wastewaters, directly from the village of Castilblanco (approximately 8.5 Tm $P.yr^{-1}$) and indirectly from the Cala reservoir which receives the wastewaters from El Ronquillo village. This has caused greater phosphorus inputs than in other reservoirs. The estimated phosphorus loadings are 0.36 $g.m^{-2}.yr^{-1}$ in Aracena , 1.22 $g.m^{-2}.yr^{-1}$ in La Minilla and 5.11 $g.m^{-2}.yr^{-1}$ in El Gergal.

When multiple regresions with the monthly data are carried out, taking the logarithm of the chlorophyll concentration as the dependent variable and considering the monthly water renewal rate, the average concentration of total inorganic nitrogen, the average concentration of soluble reactive phosphorus, and the N/P ratio, as independent variables, the following equations are found:

For Aracena: LogChl. = 1.135 - 0.268 RR - 0.0003 N (1)
($n=161$, $r^2=0.152$, MS=0.519, F=7.035, p 50.001)

For La Minilla: LogChl. = 0.47 - 0.218 RR (2)
($n=193$, $r^2=0.14$, MS=0.666, F=8.787, $p \leq 0.001$)

For El Gergal: Log CHI. = 1.116 - 0.243 RR - 0.162 P (3)
($n=118$, $r^2=0.23$, MS=1.163, F=8.456, p áO.OO1)

Only the variables with a significant correlation coefficient were considered.

When we consider the yearly averages, only the water renewal rate seems to be related with algal biomass in Aracena and La Minilla reservoirs, although this may be due to the small number of cases, as the significant level of the coefficient of N in the equation 1 is very low (p 10.05). The equations found are the following:

For Aracena: LogChl. = 1.305 - 0.384 RR (4)
($n=12$, $r^2=0.79$, MS=0.054, F=7.789, p 50.01)

For La Minilla: LogChl. = 0.671 - 0.194 RR (5)
($n=15$, $r^2=0.49$, MS=0.029, F=2.72, p 10.05)

There is no significant relationship in El Gergal reservoir, possibly due to the few years of operation of this reservoir.

Table 2 shows the correlations obtained from these parameters. In all reservoirs the higher correlation coefficients are those between the log chlorophyll and the water renewal rate as the independent variable. Relationships with the main nutrients vary among reservoirs.

In La Minilla reservoir, although there is no significant correlation between chlorophyll and nutrients, a progressive increase of the winter phosphorus input has been recorded through the years, bringing about a shift in the phytoplankton species composition (fig. 3). Thus, on diminishing the N/P ratio, the relative importance of nitrogen fixing Cyanophyceae has increased.

Figure 4 represents the simple regresion of log chlorophyll with water renewal rate obtained in each reservoir both from monthly data (fig. 4A) and annual average data (Fig 4B). It can be observed in fig 4A that most data form a compact cluster, except for a few data corresponding to very rainy months. To test whether there was a functional correlation among these parameters and no stadistic artefact existed, a simple correlation analysis was done only with data from this data cluster (RR < 2 $month^{-1}$). As a result, the correlation coefficient was lower but still significant in La Minilla reservoir (r=-0.19, p 10.01) and it was slightly lowered in El Gergal reservoir (r=-0.38, $p \leq 0.001$).

In both reservoirs, most of the monthly data which presented a water renewal rate of less than 1 $month^{-1}$ and a log chlorophyll value below 0.5, corresponded to either dry winters or to stratification periods when water was outflowed from the epilimnion.

When the average annual values are considered, a significant negative correlation between log chlorophyll and water renewal rate is maintained in Aracena and La Minilla (r=-0.56, p 10.05 for Aracena and r=-0.61, p 10.05 for La Minilla) reservoirs (fig.4B). In El Gergal the relationship is negative but not significant, probably due to the scarce data.

DISCUSSION

Although such factors as nutrient concentration in water and incoming radiation are fundamentally responsible for the algal crop, additional factors such as dilution (or water renewal), sinking and grazing can be also important. The latter two factors do not exclude recycling of nutrients back from the sediments. Hence, increasing the water renewal rate is potentially the most effective mechanism

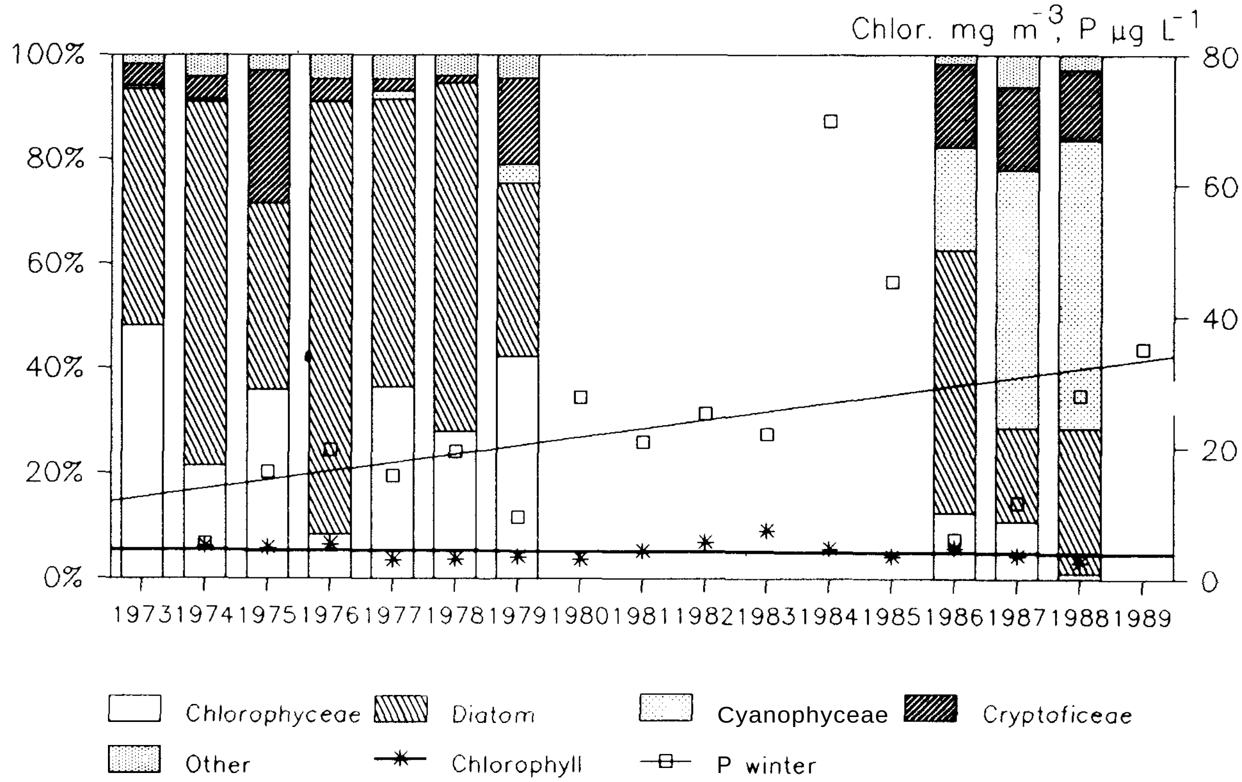

Figure 3. Tendencies of winter soluble phosphorus and chlorophyll.a concentrations and relative abundance of main algal groups in La Minilla reservoir, from 1973 to 1989.

for controlling algal growth, because biomass is thus removed from the impoundment ecosystem. The role of the flushing rate in reducing phytoplankton production has already been documented for Marion Lake by DICKMAN (1969) and in Vollenweider's models (OCDE, 1982). Other autors have indicated the inverse relationship between the algal production and water renewal rate (i.e. LERMAN, 1974; DILLON, 1975; WILLIAMS *et al.*, 1977; HERN *et al.*, 1981).

However, most of the models on eutrophication that have been elaborated, and which SERRAHIMA (1989) includes in his review, only emphasize the input of nutrients and the temperature, even when dealing with reservoirs. The residence time has only been considered when models that compare eutrophy in different water bodies have been elaborated (OCDE, 1982; HOYER & JONES, 1983). More recent models, which include hydrodynamics, do so from the point of view of its incidence in the circulation and thermic stability of the reservoirs (SERRAHIMA, 1989). Most of the models are based on data from one or few annual cycles and, in many cases, from reservoirs with little variability in their water renewal rate over the years that are dealt with. Mediterranean reservoirs, however, show great intra and interannual variations in their renewal rate. MULAMOOTTH & MC BEAN (1983) suggested that manipulation of renewal rate could help to control algal blooms in small urban reservoirs, and since 1976 we have started increasing the epilimnion renewal rate of the reservoirs, first in La Minilla reservoir and afterwards in El Gergal reservoirs, in order to slow the development of phytoplankton (TOJA, 1982). JONES & KAISER (1988) took interannual variability into account in their study in Lake Ozarks, which is influenced by several reservoirs located upstream. These authors found a negative correlation between the annual water inflow and primary production, establishing the hypothesis that in dry years there was a lower inflow of suspended solids and therefore the euphotic layer was greater, thus increasing production. However, their hypothesis did not consider that during dry years the phosphorus input was also reduced. In this sense, Lake Ozarks has a behaviour similar to La Minilla reservoir, where a decrease of suspended solids and a decrease in phosphorus input during dry years also occur.

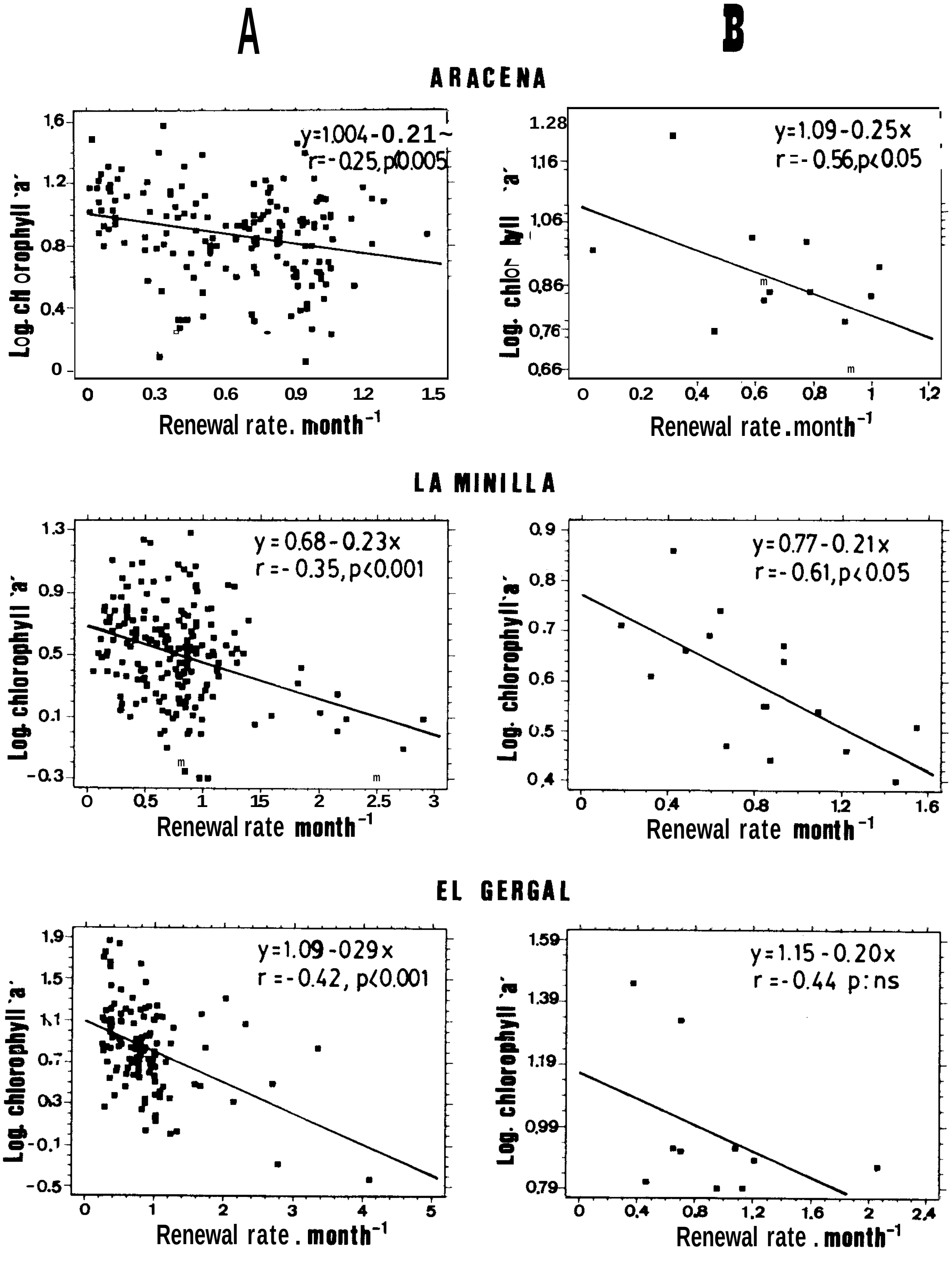

Figure 4. Linear regressions between the water renewal rate and the logarithm of chlorophyll.a concentration in each reservoir. A: using monthly data, B: using the annual average.

Table 1. Main Characteristics of the 3 reservoirs (Anual average and standard desviation). For chlorophyll only epilimnetic values was used. For inorganic nitrogen (NO_3+NO_2+NH_4) and soluble phosphorus values from all water column were used.

HYDROLOGIC YEAR	RENEWAL RATE month^{-1}		CHLOROPHYLL mg. m^{-3}		INORGANIC N pg-at. L^{-1}		SOLUBLE P pg-at. L^{-1}	
	x	σ	x	σ	x	σ	x	σ
ARACENA								
1973-74	0.32	0.06	16.20	8.90	3.58	4.59	0.42	0.33
1974-75	0.09	0.04	15.27	5.93	7.66	7.94	0.79	0.78
1975-76	0.04	0.02	9.90	4.40	34.62	24.40	0.56	0.09
1976-77	0.65	0.41	7.75	5.11	10.70	9.80	0.49	0.34
1977-78	1.03	0.13	9.00	3.83	4.66	4.39	0.33	0.24
1978-79	1.00	0.20	7.70	3.37	5.30	4.83	0.32	0.08
1979-80	0.58	0.18	10.61	3.85	2.24	2.20	0.33	0.21
1980-81			empty most of the time					
1981-82			empty most of the time					
1982-83			empty most of the time					
1983-84	0.46	0.05	5.69	5.29	39.89	18.91	1.73	1.56
1984-85	0.78	0.23	10.38	8.04	9.80	6.96	0.35	0.25
1985-86	0.79	0.07	7.90	1.63	16.31	12.60	0.21	0.20
1986-87	0.63	0.08	7.39	1.78	28.41	19.17	0.40	0.25
1987-88	0.91	0.20	6.61	4.64	28.82	23.31	0.20	0.19
1988-89	0.93	0.07	4.69	2.61	16.75	15.18	0.29	0.28
LA MINILLA								
1973-74	0.59	0.18	4.96	2.37	9.59	6.70	0.28	0.17
1974-75	0.48	0.21	4.60	2.87	35.19	23.78	0.57	0.31
1975-76	0.18	0.04	5.13	4.94	24.42	17.87	0.50	0.13
1976-77	0.87	0.52	2.79	1.62	17.81	10.20	0.50	0.36
1977-78	1.22	0.69	2.91	1.51	8.91	9.13	0.37	0.16
1978-79	1.51	0.97	3.26	2.91	10.96	10.13	0.35	0.15
1979-80	0.67	0.17	2.95	1.10	7.97	5.07	0.30	0.15
1980-81	0.32	0.11	4.13	2.94	26.42	13.30	0.55	0.27
1981-82	0.64	0.28	5.52	3.22	40.80	27.44	0.52	0.35
1982-83	0.42	0.08	7.25	5.34	29.17	17.84	0.88	0.24
1983-84	0.93	0.26	4.42	4.68	26.74	13.13	1.05	0.89
1984-85	1.09	0.57	3.47	1.90	7.37	6.19	0.53	0.45
1985-86	0.93	0.22	4.74	2.54	12.16	7.78	0.22	0.20
1986-87	0.84	0.16	3.54	2.05	26.94	17.32	0.24	0.20
1987-88	1.45	1.02	2.54	2.07	27.39	13.91	0.42	0.37
1988-89	0.85	0.26	3.58	3.41	29.32	21.66	0.50	0.37
EL GERGAL								
1979-80	0.95	0.09	6.22	4.00	5.99	5.88	0.48	0.28
1980-81	0.46	0.21	6.55	0.35	9.22	9.10	0.92	0.77
1981-82	0.65	0.23	8.29	7.61	26.16	22.16	1.24	0.96
1982-83	0.37	0.14	28.58	23.04	24.45	23.50	0.34	0.20
1983-84	1.13	0.48	6.24	4.95	58.58	13.74	1.42	0.79
1984-85	1.21	0.94	7.68	4.54	13.70	9.61	0.94	0.50
1985-86	1.08	0.58	8.40	5.13	19.09	9.82	0.39	0.22
1986-87	0.70	0.21	21.32	20.74	40.25	24.45	0.86	0.52
1987-88	2.06	1.98	7.38	5.81	39.98	39.89	0.58	0.57
1988-89	0.70	0.34	8.30	6.76	38.99	30.71	0.71	0.38

The negative relationship between algal biomass and water renewal rate is expected since an increaae in the latter implies an extraction of biomass from the reservoir, especially if epilimnion water is extracted preferently. as it happened in La Minilla reservoir (since 1976) and in El Gergal reservoir (since it came into service). the two reservoirs that show the highest correlation coeficient between these two factors. An increase in the renewal rate can also lead to a losa of nutrients (LERMAN, 1974), which may determine a drop in biomass in the following months. In years with high rainfall during the mixing period there will be a lower production during the stratification period, and average annual biomass will be lower than in drier years.

In Aracena reservoir, an increase in water renewal rate leads to a reduction in phosphorus concentration (negative correlation between RR and P in table 2). Despite this negative relationship, there is no relationship between soluble phosphorus and log chlorophyll. In this reservoir we find a negative relation between nitrogen and log chorophyll, since the largest algal crops can be related to Cyanophyceae blooms, when N/P ratio is low (below 10). Although, equation 1 does not include the N/P ratio, a negative correlation exists between log chlorophyll and N/P ratio (table 2). In the first years of the study there was a relatively high phosphorus concentration, higher than in La Minilla reservoir, due to the nutrients released from the flooded terrestrial vegetation when the reservoir was first filled. On the springs of these first years the nitrogen was rapidly removed from the epilimnion (due to phytoplankton uptake) and from the hypolimnion (due to denitrification), thus favouring the proliferation of nitrogen fixing Cyanophyceae in summer (TOJA, 1976; 1984). The initial nutrient stock did not increase, as the reservoir's catchment area is small and in a good state of conservation. Consequently, water inflow during wet years contributed to the dilution of these nutrients and their removal from the reservoir, which, except on rare occassions, takes place through the outlet at the bottom. We can conclude that in Aracena reservoir nutrients seem to have been controlling algal biomass, although lately they have less importance than the water renewal rate (equations 1 and 4).

In El Gergal reservoir, although the water renewal rate is still the most important factor, phophorus concentration also seems to determine algal biomass and, probably because this reservoir has a continuous input ofthis element (17.9 $Tm.yr^{-1}$), the soluble phosphorus concentration appears with a significant coeficient in equation 3. Nevertheless, relationsiphs between algal biomass and phosphorus concentration are negative. This can be partly due to a statistical interference. In El Gergal reservoir, an increase in water inflow leads to an increase in phosphorus concentration as it is shown by the positive correlation between RR and P (table 2) since it receives waters with high phosphorus concentration (see above). The strong negative correlation between the water renewal rate and the algal biomass, together with the negative correlation between water renewal rate and phosphorus may consequently produce a negative correlation between phosphorus and chlorophyll.

El Gergal reservoir bears a higher P loading, which favours phytoplankton growth in such a way that algal biomass reachs the highest levels of the 3 reservoirs during spring proliferations. However, its high water renewal rate makes algal biomass decrease or remain the same during the rest of the stratification period (approximately 7 months). Also, the nitrogen fixing Cyanophyceae blooms did not take place during summer as it happened in Aracena reservoir during its first years of operation, although a nitrogen deficit can also be detected in El Gergal reservoir during the summer. This is due to the management of this reservoir, with water extractions taking place from the epilimnion during the stratification period. This artificial increase of the water renewal rate from the productive layer resulted in a continuous decrease of the algal biomass, thus preventing algal blooms. Therefore, the highest algal crop is not registered when the N/P ratio is lower and thus, there is no negative correlation between algal biomass and nitrogen , as it happened in Aracena reservoir. Then, the average chlorophyll concentration in El Gergal reservoir is similar or everlower than in Aracena reservoir, in spite of the highern phosphorus input in El Gergal reservoir. Nevertheless, this P loading not being excessively high can be almost totally consummed very rapidly. Then, the concentration of soluble phosphate is rather low during the stratification period, accounting for the negative correlation between P and algal biomass (table 2).

There is not significant correlation between water renewal rate and nutrients in La Minilla reservoir (table 2). It has a larger catchment area and the nutrients input can vary a great deal as the inflow also varies, that is, it depends on how rainfall is distributed. If, after several dry years, a large water inflow occurs, the nutrients input (especially phosphorus) increases very much. This happened, for example in 1976-77 (phosphorus loading was 2.12 $g.m^{-2}.yr^{-1}$) and in 1983-84 (4.33 $g.m^{-2}.yr^{-1}$). There was also an increase in the proportion of suspended solids (as in Ozarks lake), but they soon settled and during the stratification period (7 -8 months long, aproximately) the amount of inorganic seston was

Table 2. Significant correlations between the different parameters analyzed in each reservoir using monthly data. RR= water renewal rate $month^{-1}$, N= inorganic nitrogen ($NO_3+NO_2+NH_4$) µg-at. L^{-1}, P= soluble phosphorus µg-at. L^{-1}, N/P ratio between inorganic nitrogen and soluble phosphorus

Dependent variables	independent variables			
ARACENA (N = 162)	RR	N	P	N/P
logchl.	-0.25***	-0.23***		-0.15*
N			0.31****	0.33****
P	-0.33****	0.31****		-0.26****
N/P	0.23***	0.33****	-0.26****	
LA MINILLA (N = 193)	RR	N	P	N/P
logchl.	-0.35****		-0.15*	
N			0.17*	
P		0.17*		
N/P			-0.26****	
EL GERGAL (N = 118)	RR	N	P	N/P
logchl	-0.42****		-0.33****	
N				0.33****
P	0.31****	0.33****		-0.27***
N/P			-0.27***	

**** $p \leq 0.001$
*** $p \leq 0.005$
** $p \leq 0.01$
* $p \leq 0.05$

similar to the drier years (CASCO, 1990). In drier years, with lit tle water inflow, there was a small phosphorus loading, i.e. in 1982-83 (0.22 $g.m^{-2}.yr^{-1}$) (fig. 3).

In La Minilla reservoir, only the water renewal rate determines algal biomass, nutrients not seeming to have any importance (equations 2 and 5). However, from 1973 to 1989, the phosphorus input into the reservoir tended to increase (fig. 4); firstly because of the removal of natural vegetation upstream in order to plant Eucalyptus (fig. 1) in 1976 (TOJA, 1984; TOJA *et al.*, 1983), secondly, because of the effect of the construction of the Zufre reservoir, and after, because of the release of the nutrients stocked in this reservoir that were sent with water downstrean to La Minilla reservoir (CASCO, 1990). However, the phytoplankton biomass tended to remain at the same level and even, to fall slightly, due to the high natural water renewal rate as well as to an increase in the epilimnion renewal rate, caused by the opening of the reservoir's upper outlets (TOJA, 1982).

However, the composition of the phytoplankton has changed appreciably (fig. 3). Cyanophyceae, especially nitrogen fixative types, used to be very scarce in this reservoir (TOJA, 1984). As far back as 1977-79, they began to appear in higher proportions than during the previous years (TOJA *et al.*, 1983). In 1986-89 (CASCO, 1990) with the building and coming into service of Zufre reservoir, the population has changed noticeably, with a predominance of Cyanophyceae during the stratification periods.

In Mediterranean reservoirs with a continuous phosphorus input much greater than the one El Gergal reservoir receives, the importance of the mentioned factors can be the opposite. The Sau reservoir (on the river Ter in Catalonia) is the reservoir where the longest series of data have been recorded in Spain, as it has been studied continuously since 1963 (VIDAL, 1976; ARMENGOL, 1988; ARMENGOL *et al.*, 1986; ARMENGOL & VIDAL, 1988). It has a similar water renewal rate than the Seville's reservoirs (2.12-7.50 yr^{-1}) and it has been receiving increasing amounts of phosphorus every year since it came into service (from 30 $Tm.yr^{-1}$ in 1965 to 215 in 1985), with an average loading of 26 g $m^{-2}yr^{-1}$ while the water renewal rate fluctuates with time. Using data obtained from ARMENGOL (1988), the equation of multiple regression bet-ween the log chlorophyll, the annual water renewal rate (yr^{-1}) and the soluble phosphorus has been calculated as follows:

$$\text{LogChlo.} = 0.460 + 1.504\,P + 0.068\,RR$$
$$(n=21,\ r^2=0.56,\ MS=0.449,\ F=12.44,\ p \leq 0.001)$$

In this case phosphorus is the factor more correlated with algal biomass. Even when considering the water renewal rate it seems to be different to the Seville's reservoirs. For example, with water renewal rates that were high and similar in 1971 and 1982, concentrations of P in the reservoir were 123 and 240 $\mu g\ L^{-1}$ respectively, which meant a greater algal biomass in 1982. When comparing the evolution of the water renewal rate and the chlorophyll concentration, we can see an inverse relationship, though not significant ($r=-0.12$, p: n.s.). Yet there is a significant inverse relationship as far as phosphorus is concerned ($r=-0.46$, $p \leq 0.05$).

That is to say that an increase in the water renewal rate always tends to diminish algal crop, even though the behaviour of each reservoir throughout its life is different according to the nutrients input from its catchment area. In reservoirs where this contribution is low, the water renewal rate is the main controlling factor as far as the eutrophic state is concerned (and may be the only one, as in the case of La Minilla reservoir), while if the amount of phosphorus increases, its relative importance in algal biomass increases as well until it completely overlaps the effect of the water renewal rate (as in the case of Sau reservoir). As REICHLE *et al.* (1980) have pointed out: biomass in ecosystems depends on two factors: environmental favourability (in this case, nutrient availability) and disturbance. When disturbance that destructs biomass is very frequent (as a high water renewal rate), it may be the main factor controling biomass, counteracting the positive effect of the habitat favourability.

It is dificult to determine the phosphorus threshold input above which the phosphorus loading becomes the main controlling factor. DILLON (1975) found that Cameron Lake (Ontario), with a phosphorus loading of 1.7 - 2.21 $g.m^{-2}.yr^{-1}$, was not eutrophic owing to its high flushing rate. The results obtained from Sevilla's reservoirs suggest that when the phosphorus loading remains at low levels (less than 2 $g.m^{-2}.yr^{-1}$) the water renewal rate is the controlling factor of algal biomass, even if the nutrient concentration and N/P ratio affect the qualitative composition of phytoplankton. However, when the phosphorus loading is higher, it becomes the dominant factor controlling algal crop, although the renewal rate is still significant.

This rapid control effect of water renewal rate on algal biomass has been and is still used to manage the water supply reservoirs of Sevilla (La Minilla and El Gergal reservoirs). During the stratification period water is preferently extracted from the epilimnion thus, increasing proportionally the water renewal rate of the photic zone (TOJA, 1982) and keeping algal biomass at a lower level than the one that could be expected from the nutrient concentration in the water. Also, during the mixing periods, when outflow operations are needed in El Gergal reservoir (in wet winters), the water is extracted from the outlet at the botton, increasing the hypolimnion renewal rate and removing nutrients from the reservoir. This water management has improved the water quality and therefore has implied a great economical advantage for the drinking water supply management to Seville city (TOJA, 1982, 1984).

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