THE COASTAL LAGOON ALBUFERA DE VALENCIA: AN ECOSYSTEM UNDER STRESS

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ABSTRACT

Recent studies (1980-88) on the Albufera of Valencia show that this shallow oligohaline coastal lagoon is an ecosystem under stress. Domestic and industrial waters loaded with phosphorus and ammonium reach the lagoon from the northern side. Nitrate-rich agricultural waters arrive mainly from the southern side. The estimated nutrient loadings are: Total P ≈ 39 g $m^{-2}yr^{-1}$, dissolved P ≈ 14 g $m^{-2}yr^{-1}$, N-NH_4^+ ≈ 74 g $m^{-2}yr^{-1}$ and N-(NO,-+NO;) ≈ 81 g $m^{-2}yr^{-1}$.

The stress produced in the Albufera by these P and N inputs is seen by the strikingly high values of chlorophyll concentration and primary production, only comparable with the most hypertrophic lakes in the world. Chlorophyll *a* has an average value around 300 µg l^{-1}, with a phytoplankton density of 10^5 to 10^6 ind ml^{-1} corresponding to a biomass of 30-300 mg l^{-1} (fresh weight). The primary productivity, restricted to the lagoon surface, has been roughly estimated at 1.7 kg $m^{-2}yr^{-1}$. This phytoplankton growth implies a nutrient consumption which results in very low nutrient concentrations in the lagoon water and the outlets. One half of the extraordinary biomass yield is then recycled and the other half exported to the sea (20 %) and to the sediments (30 %).

Phytoplankton is generally constituted by filamentous cyanobacteria at 80 %. The most frequent succession pattern of these algae was a winter-spring dominance of *Planktothrix agardhii* and a summer dominance of *Geitlerinema* sp. Between their maxima *Pseudanahaena galeata* peaks in spring and autumn.

During the greater part of the year, zooplankton is almost exclusively constituted by *Brachionus angularis*, a rather detritivorous filter feeder, and its predator *Acantocyclops vernalis*. The average annual zooplankton biomass, around 2 mg l^{-1}, is quite high, but in relation to phytoplankton biomass it is very small (≈ 1 %).

INTRODUCTION

The Albufera of Valencia is a shallow coastal lagoon situated 12 km south of the town of Valencia, Spain (UTM 30S YJ 2857).

This lacustrine system, Natural Park since 1986, was originated by the enclosure of a bay behind a beach bar 30 km in length. The bar rises at the mouth of the river Turia, its distal end being attached to the cliffs at the cape of Cullera. Studies realized on the continental shelf as well as calco-arenitic remains located in the bar suggest that the Holocene sediments lie on a previous Pleistocene bar. The Holocene bar has formed from sediments mainly carried by the river Turia, and it reaches a width of 500 to 1000 m. Two parallel dune systems, now covered by Mediterranean vegetation (Devesa del Sales), are developed on the bar. The final closing of this beach bar occurred around 6000 B.P. (ROSSELLO, 1972; SANJAUME, 1985).

In Roman times, the primitive lagoon covered an area of 300 km^2 according to coetaneous descriptions (Rufo Festo Avieno). Since then, the regression has been important, yet it was in the second half of the 19th century when it was performed most drastically by filling 60 % of the lagoon then existent to gain land for rice cultivation (fig. 1). Today the lagoon occupies an area of 23.2±0.1 km^2 (Landsat-5). surrounded by 223 km^2 of rice fields and a few small residual marshland areas (CAVANILLES, 1795; ROSSELLO, 1972, 1976).

The Albufera, originally saltwater-filled, became progressively less saline when the closing process finished, leaving a lagoon independent of the sea. At the end of the 18th century. hydraulic works associated with the agricultural

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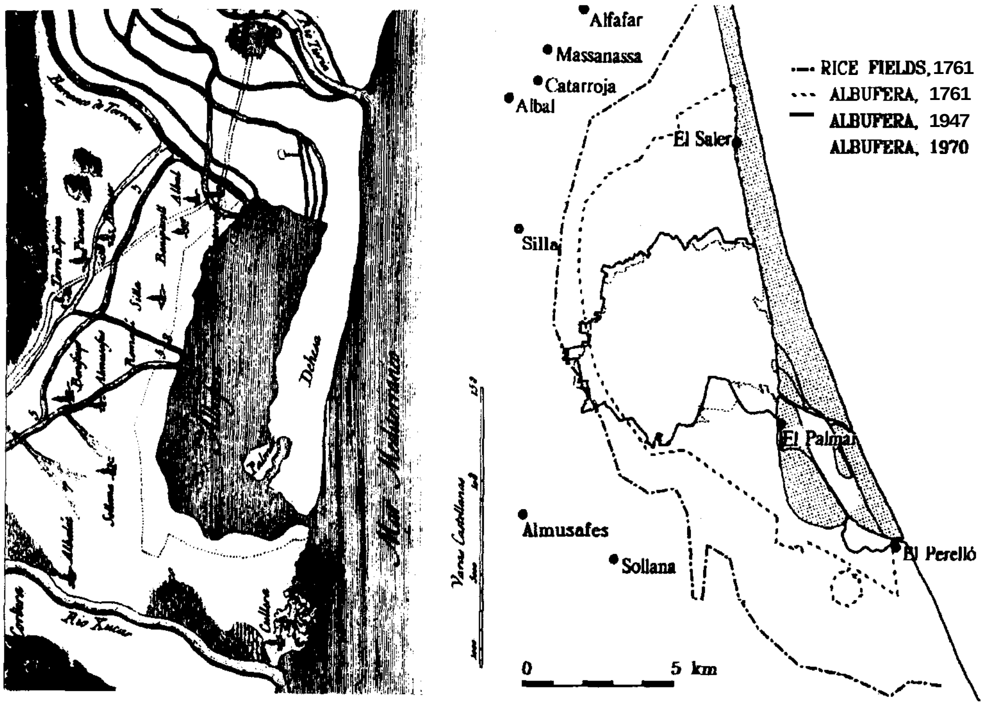


Figure 1. Engraving of the Albufera of Valencia at the end of the 18th century from CAVANILLES (1795) (left). Outline of the rice fields in 1761 and the Albufera lagoon in 1761 and at present (1947, 1970) from ROSSELLO (1972) (right).

land uses not only increased freshwater intlow to the lagoon but also outflow through a channel which was opened as an artificial outlet to the sea, Pujol Vell. This channel, dug in 1762 and reconstructed several times after 1862, became definitely inoperative at the end of the 19th century (MOMBLANCH, 1960).

The increasing conversion of the old Albufera into rice fields put some of the natural water outlets, located at the southern side of the lagoon, out of service; so another two channels were opened during the first half of the 20th century (Pujol Nou and Perellonet). The 18th century brackish water lagoon has come to be today's oligohaline Albufera of Valencia. These changes in salinity were revealed by studies of sediment diatoms (MARGALEF & MIR, 1973) and mollusc fauna (ROBLES er *al.*, 1985).

At present, water inflow takes place through some brooks and a series of channels dug for rice field irrigation. The lagoon is also freshwater-fed by springs located either within the lagoon or in the surrounding marshland. Water outlet goes through three main channels (Pujol Nou, Perellonet and Perelló) which link the lagoon with the sea (figs. 1 and 2), the flow being controlled by a system of sluicegates because the whole lagoon acts as a regulation reservoir in accordance with rice cultivation periods. This manipulation influences the annual cycle and the lagoon water level.

The lagoon and marshlands of the Albufera traditionally have been used for rice cultivation, fishing and hunting, but only recently the lagoon water has experienced severe changes. In the 60ies the lagoon was clear to the bottom and magnificent subaquatic prairies could be seen from the surface. Human population in the drainage area was then slightly over 200,000 and industries did not number more than 500. However, in just one decade the population almost doubled in size while the industries multiplied by ten. The Albufera has been and still is the great depurative of all the sewage of the catchment area. Water enters the Albufera with high levels of nutrients and leaves it nutrient-free, although laden with cyanobacterial biomass.

Macrophytes have totally disappeared from the Albufera because of the extraordinary growth of plankton, which keeps off the light required for macrophyte photosynthesis. The lagoon now presents permanent blooms of non-N-fixing cyanobacteria.

Along with macrophytes, the interesting benthonic invertebrate fauna with several endemics also has disappeared. The small endemic ciprinodont *Valencia hispanica* and the commercially appreciated sea bass species *Dicentrarchus labras* have vanished and eels are becoming scarce. Only *Mugil cephalus* and *Cyprinus carpio* are abundant at present. The important bird sanctuary that this environment was once is only history now. Fifteen years ago, plankton formed a diverse community characteristically constituted by diatoms, although green algae also were important in summer. First data on chlorophyll *a* concentrations indicate that their annual mean was about 13 µg l^{-1} in 1972, 25 µg l^{-1} in 1973 and 54 µg l^{-1} in 1974 (DAFAUCE 1975). Recently, however, the chlorophyll *a* concentrations in the lagoon water have increased to levels of up to 400 µg l^{-1} and the phytoplankton has suffered the sudden general changes described in water quality deterioration, i.e., replacement of green algae by cyanobacteria in eutrophic lakes and competitive interaction between N-fixing and non-N-fixing cyanobacteria in hypertrophic lakes.

Today the catchment area is heavily polluted; it includes more than 30 towns with a total of over 400,000 inhabitants and houses more than 4,000 industries of all types. Sewage and industrial discharges go directly into the brooks and irrigation channels and on to the lagoon, where they produce high levels of eutrophication and seriously endanger the system.

Despite the extension and naturalistic importance of the Albufera, only a few limnological studies have been realized so far. PARDO (1942) published a general monograph on the Natural History of the Albufera, summarizing the first limnological data. DAFAUCE (1975) reviews the results of a series of studies carried out during the years of 1972-74, laying emphasis on the eutrophication process which was under way. The present paper aims at summarizing some of the authors' recent studies on the characteristics of the Albufera and at offering a model of the functioning of this hypertrophic lagoon.

METHODS

The methodology used for obtaining the data of this paper is included in several works of the authors (SERRA *et al.*, 1984; MIRACLE *et* al., 1984a, 1987; OLTRA & MIRACLE, 1984, 1992) and other publications of the scientific literature.

The water samples of the Albufera were taken at different depths by means of a 2.6 l capacity Ruttner hydrographic bottle. Conductivity, temperature, pH, Eh and dissolved oxygen were measured "in situ" with the corresponding instruments. The major chemical parameters were determined according to the methodology described by GOLTERMAN *et* al. (1978). Water transparency was measured with a Secchi disk and direct measures of light penetration were taken with an underwater radiometer (PAR measurements).

The photosynthetic pigment content of the samples was evaluated spectrophotometrically, applying the equations proposed by LORENZEN (1967) and STRICKLAND & PARSONS (1972), once the algal cells had been retained in Whatman GF/F filters and their pigments were extracted with a mixture of acetone 90% and DMSO in a 1:1 ratio (SHOAF & LIUM, 1976). Primary production was determined by adding 10 µCi of sodium bicarbonate ^{14}C to transparent and opaque 125 ml bottles filled with lagoon water, which were incubated at the sampling site for one hour. After having filtered the water through Whatman GF/F filters, the carbon incorporated as particulate (POC) and dissolved (DOC) organic compounds was counted in a scintillation counter (MAGUE *et al.,* 1980; MIRACLE & VICENTE, 1985).

Lugol preserved samples of phytoplankton were observed according to the UTERMÖHL (1958) technique for enumeration.

To collect zooplankton, the contents of the 2.6 l Ruttner bottle were filtered through a 50 µm Nytal mesh and preserved in 5 % formalin, to be counted afterwards with an inverted microscope at 100 or 200 X magnification.

The specific techniques for studying populations of aquatic bacteria can be looked up MIRACLE *et al.*, (1992). Epifluorescence techniques revealing the autofluorescence of photosynthetic pigments (CRAIG, 1987) may be used in the counts for easily distinguishing filamentous or small cyanobacteria from morphologically similar organisms without chlorophyll (generally heterotrophic bacteria).

RESULTS AND DISCUSSION

Water input

The Albufera lies at the end of a 917.1 km^2 catchment area. Water flows to the Albufera from several brooks, only two of them - Massanassa and Beniparrell, which are also the most important ones - directly issuing into the lagoon in its northern part. Other running waters drain into several irrigation channels in the southern part. Besides, the Albufera is supplied with groundwater springing from the surrounding marsh ("ullals") and from the bottom of the lagoon. Finally, apart from direct input by precipitation, the Albufera also is supplied with water coming from human use, i.e., irrigation water and sewage of the surrounding townships that flows through a complex system of irrigation channels. As regards irrigation water coming from the rivers Turia and Júcar, each year 321.86 Hm^3 of water transferred from the Acequia Real del Júcar and 59.27 Hm^3 ceded from the Acequia de Favara (river Turia) reach the Albufera or pass directly into the sea.

To evaluate the real amount of water flowing into the lagoon we have measured directly the flux in the 64 water courses (two brooks: Massanassa and Beniparrell, and 62 irrigation channels). For 1988, the total inflow to the Albufera was estimated to be 280 $Hm^3\ yr^{-1}$ (table 1). Despite the high number of inflow points, only a few of them are really important with regard to water input. These are particularly Overa and Dreta - which represent more than 40 % of the inflow - followed by the Carrera del Saler, the Alqueresía, the Fus channel and the brooks of Beniparrell and Massanassa, their joint contribution to the total inflow being virtually 75 % (fig. 2). Considering the meteorological data of 1988, the Albufera presents a negative evaporation-precipitation balance, with a difference of 15 Hm^3 of water evaporated and not compensated by precipitation on the surface of the lagoon. So the net water input is at least 265 $Hm^3\ yr^{-1}$, which corresponds to an average water renewal rate of ten times a year. However, large differences are observed with respect to the inflow in different sectors of the lagoon, making water turnover slow in extensive zones of the Albufera (once or twice a year in the northwestern and western parts) while the sectors proximate to the outlet channels (northeast and southeast) may come up to a mean turnover time of 15 days (fig. 2). These mean values are subject to water manipulations derived from the cycle of rice cultivation. Consequently, renewal times are shorter at periods of important water flow (spring and autumn) and longer when water is being retained (winter and summer).

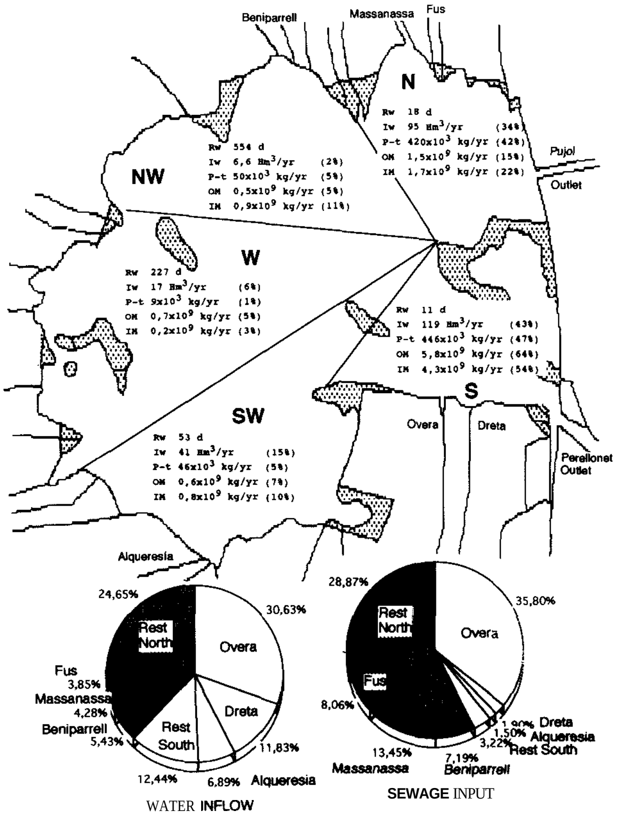


Figure 2. Zonal heterogeneity of the Albufera lagoon due to differences in water renewal time. Residence time (Rw), water inflow (Iw), total phosphorus input (P-t), suspended organic matter input (OM) and suspended mineral matter input (IM) into each zone are indicated. Below, pie diagrams showing the contribution of the main northern (shaded sectors) and southern (unshaded sectors) water courses to the total water inflow and sewage input into the Albufera.

Hydrochemistry

Considering the typology obtained from a global study of the coastal Mediterranean wetlands of Spain (LOPEZ & TOMAS, 1989). the Albufera of Valencia would correspond to the more extreme range of the oligohaline and eutrophic type (fig. 3). The ionic proportions (in chemical equivalents) correspond to characteristics which are much closer to those of freshwater than of marine water. Thus, the concentration of sulphates is quite similar to that of chlorides and in many cases even higher. Ca^{++} is present in proportions which may equal Na^+ in some instances. Ca^{++} and Mg^{++} concentrations are normally very similar, although Ca^{++} presents slightly higher values in most cases. The Albufera waters correspond to the following relations: $SO_4^{=} >< Cl^- >$ AIK and $Na^+ >< Ca^{++} >< Mg^{++} > K^+$.

This section summarizes the data from SERRA *et al.* 1984, MIRACLE *et al.*, 1987, SORIA *et* al., 1987 and a technical report on the sewerage project of the Natural Park of the Albufera de Valencia (MIRACLE *et al.*, 1989).

Conductivity (fig. 4) has an annual cycle associated with human manipulation of the lagoon according with the rice farming cycle. There are two periods of low conductivity, which correspond to the opening of sluicegates and thus to flowing water. These periods lie in the months of March-April and September, dedicated respectively to the tilling and sowing and the harvesting of rice. In summer and winter

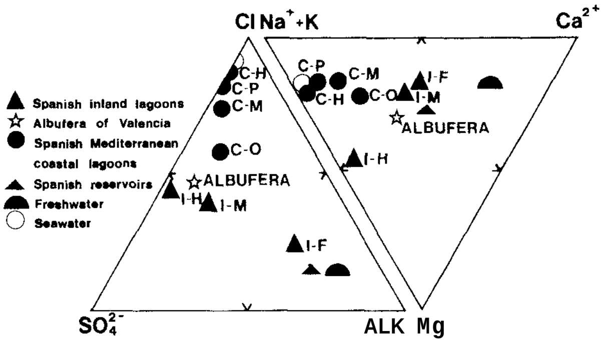


Figure 3. Average ionic composition of the Albufera of Valencia waters as compared with other Spanish Mediterranean coastal wetlands (C) and inland waters (I). Points are defined by the equivalent percentages of major anions and cations (H: hypersaline, P: polyhaline, M: mesohaline, 0 : oligohaline, F: freshwater). For coastal wetlands salinity categories (in ppt) are: C-O $\leq$ 5; C-M 5-18; C-P 18-40; C-H $\geq$ 40. Modified from LOPEZ & TOMAS (1989).

conductivity reaches higher levels as dams are closed and water flux is low. The flux is lower in winter than in summer because the rice fields require a slight water flow in summer.

On the other hand, the values found for the rest of the parameters are conditioned by the high primary production of the lagoon. Thus it presents: 1) a very low alkaline reserve (1-3 meq l^{-1}), 2) an extraordinarily high pH (8.5-10.5) with a marked daily and annual cycle, and 3) fluctuating but normally over-saturated oxygen levels, although the redox potential is always low (350-390) as a consequence of the large amount of organic compounds present in the water.

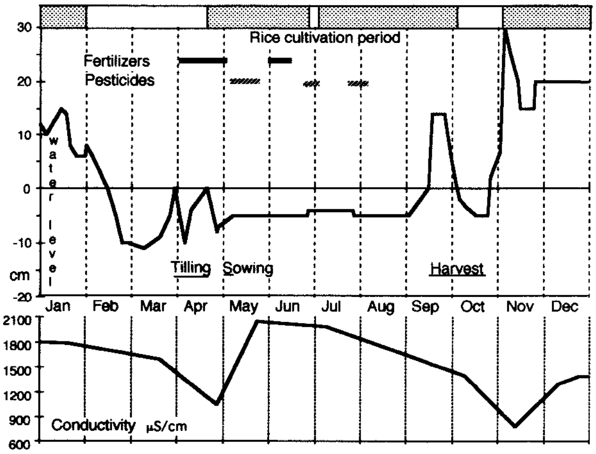


Figure 4. Water level and conductivity during the annual cycle of 1988. The timing of major rice farming activities is indicated. The cycle is conditioned to precipitations (important that year in January. April, June, September and November) and the sluicegate regulation according to the needs of rice farming. Shaded periods (top of the graph) indicate when rice fields are flooded.

The nutrient concentration of the Albufera is balanced between input and consumption by plankton. So the mean N concentration in the lagoon was higher than 30 μM in winter, declined in summer and was lower than 1 μM in September. This variation is attributed to spring algal proliferations which consume the available nitrate. The highest nitrate values occurred in the southern irrigation channels as a consequence of the leaching of agricultural fertilizers, particularly in the Overa channel (maximum value 807 μM in the period of 1985-88).

Nitrite presented moderate values, with extremes encountered in the Overa channel (69 μM during 1985-88) as a consequence of the transformations of nitrogen compounds in sewage-polluted agricultural waters.

Ammonium was found in water courses heavily charged with urban sewage, such as Massanassa and Carrera del Saler, as well as in the zone of discharge and influence of these channels. The brook of Massanassa, having usually reducing conditions (Eh < 50 mV), had all N present in reduced form. An increase in the amount of ammonium was observed through the years. Maximum concentrations of 2200 μM were observed in the winter-spring period of both the 1985 and the 1988 annual cycles.

Phosphorus displayed its maximum values at the same sites as ammonium, i.e., in the polluted irrigation channels and brooks of the northern part. Soluble phosphate maxima of 185 μM and 215 μM were found in the brook of Massanassa in January in the annual cycles of 1985 and 1988 respectively. Within the Albufera, free inorganic phosphorus is minimal as all entries are incorporated into the extraordinary algal biomass.

When these concentrations are represented in terms of absolute values of nitrogen and phosphorus supplied to the lagoon, and taking into account the flux of the affluent channels, the 1988 data yield numbers as high as 4000x10^3 kg yr^{-1} of inorganic nitrogen, 372x10^3 kg yr^{-1} of soluble

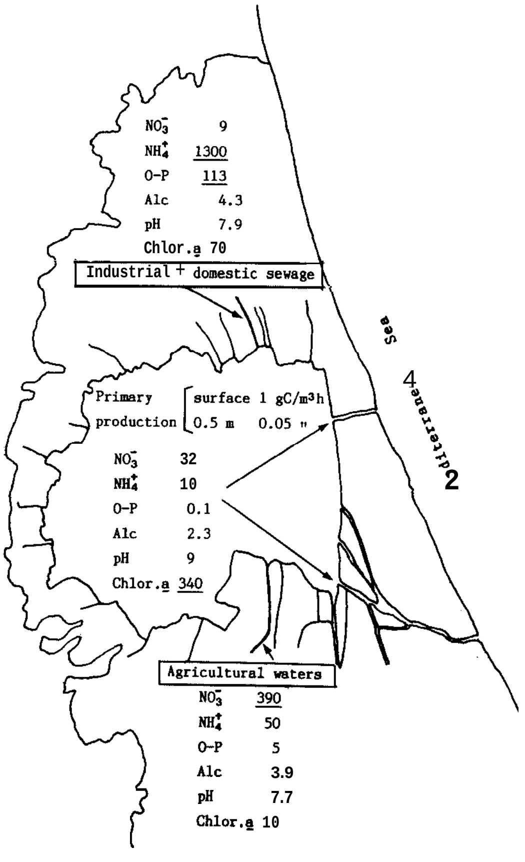


Figure 5. Outline of the Albufera of Valencia and rice fields area indicating the 1985 annual average of nutrients and other parameters related to phytoplankton growth. From top to bottom: Northern channels and brooks with sewage-polluted water, Albufera lagoon, and Southern channels with agricultural waters. Nitrate, ammonium, dissolved phosphorus in μmol l^{-1}, alkalinity in meq l^{-1} and chlorophyll *a* in μg l^{-1}. From MIRACLE (1988).

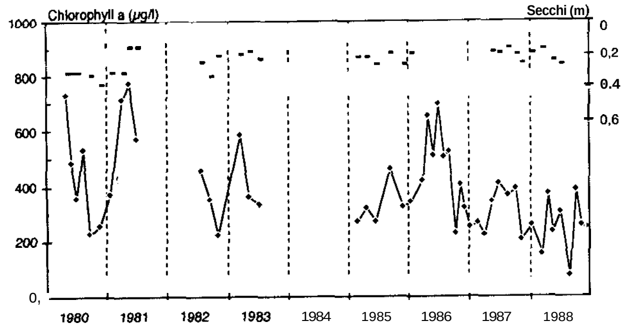


Figure 6. Chlorophyll a and Secchi disk variations during the years 1980-88.

phosphorus and 1000×10^3 kg yr^{-1} of total phosphorus. The major part of these inputs comes from waste water, with an estimated annual inflow to the Albufera of 78.6 Hm^3 (28 % of the total water input of the lagoon).

Thus, the channels and brooks arriving from the north are heavily polluted with industrial and domestic sewage and those from the south mainly with agricultural waters and some village effluents. Fig. 5 shows the mean nutrient and chlorophyll a concentrations of the northern water courses in comparison with their southern counterparts and the water of the Albufera lagoon. Domestic and industrial effluents are charged with phosphorus and ammonium, while agricultural waters are rich in nitrates. On the other hand, the water within the Albufera has relatively low concentrations of nutrients. However, the stress produced in the lagoon by the charge of nutrients is shown by the extremely high chlorophyll contents and primary production values (fig. 6 and table 3). Other parameters associated with primary production, such as pH and alkalinity, vary accordingly; they are respectively high and low inside the lagoon.

The samples, characterized by the physicochemical and biological variables indicated in fig. 7, were subjected to a principal component analysis. The first component can be associated with eutrophy: the values of photosynthetic pigments, seston and oxygen are highest at the positive end while nutrients, alkalinity and light penetration have their peak values at the negative end. Thus Albufera samples are distinguished from channel samples. The second component is determined by orthophosphate, ammonium, alkalinity and salinity at the positive end versus nitrate, nitrite oxygen, redox and light penetration at the negative end, thereby making a distinction between the northern and the southern water courses.

Global model for the functioning of the Albufera, based on phosphorus flux and balances

A study of nutrient flow and balances was realized in 1988, based on seasonal measurements of flux and nutrient concentration in the 36 main inflowing and three outflowing channels,

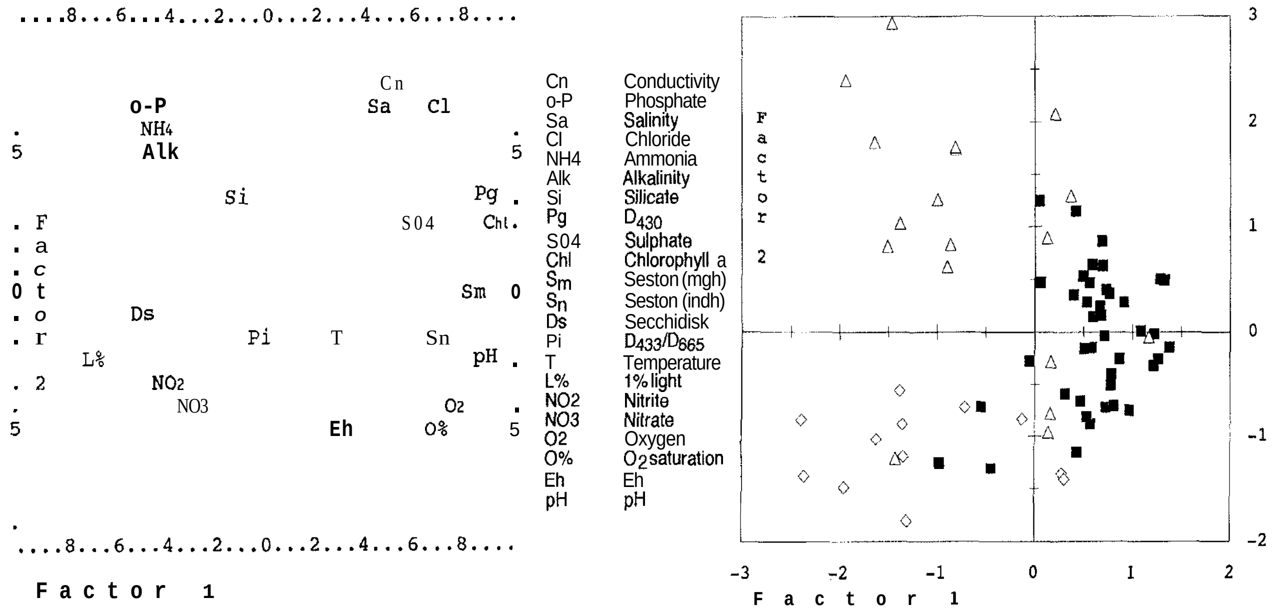


Figure 7. Principal component analysis of the physico-chemical characterization of several locations inside the Albufera lagoon and in the main channels inflowing from the north and from the south, at different times during 1985. Position of the physico-chemical variables (left), defined by the correlation coefficients with the axes and the samples (right) in the space defined by the first two principal components (Factor 1 and Factor 2, which account for 52 % of the variance). Modified from SORIA *et* al., (1987a).

Table 1. Global nutrient flux and pollution. Inorganic and organic N. dissolved and particulate P and sewage input. 28 % of the total water inflow into the Albufera of Valencia are sewage water.

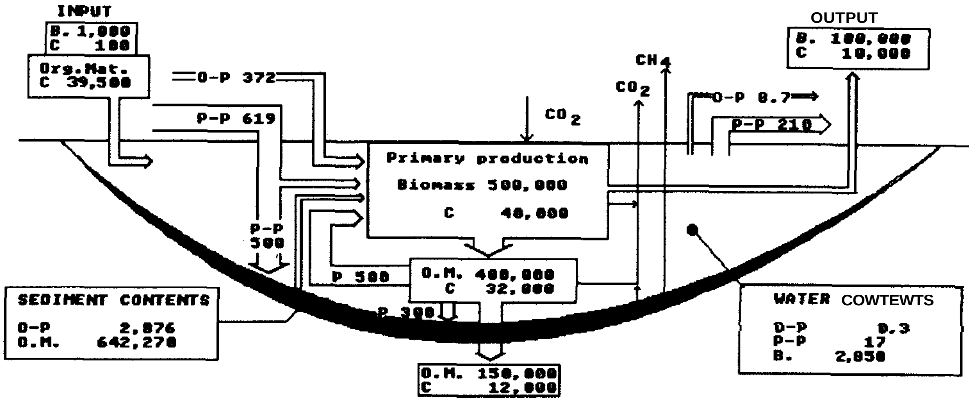
	$N\text{-}NH_4^+$	$N\text{-}NO_2^- + NNO_3^-$	N-org	$P\text{-}PO_4^{3-}$	P-part	Sewage
INFLOW CHANNELS						
10^3 kg yr^{-1}	1907.9	2076.9	4335.1	371.8	619.3	78.6 Hm^3yr^{-1}
g $m^{-2}yr^{-1}$	74.3	80.8	168.7	14.5	24.1	3.1 $m^3m^{-2}yr^{-1}$
OUTFLOW CHANNELS						
10^3 kg yr^{-1}	178.8	191.8	1470.0	8.7	210.0	
g $m^{-2}yr^{-1}$	7.0	7.5	57.2	0.3	8.2	

as well as inside the Albufera (MIRACLE, VICENTE & SORIA, 1989). The data of this study have been used to elaborate a model of the functioning of this ecosystem (table 1, fig. 8).

The annual nutrient inputs of the Albufera of Valencia are extremely high because the inflowing channels receive sewage water without treatment along their way. We estimate that the proportion of sewage in the water that enters the Albufera is 28 % of the total water inflow. This proportion has been calculated by measuring the P content at the exit of the sewage drains from villages around the lagoon; this value has been used as a reference for deducing the sewage content by the P concentration at the channel mouths in the Albufera (table 1, fig. 2).

The concentration of nutrients in the Albufera water is very low, as well as its inorganic nutrient output. Inorganic N and P outputs are respectively 10 and 50 times less than their corresponding inputs. The entrance of particulate P is mainly due to organic matter, while the outflow is mostly constituted by phytoplankton biomass (fig. 8).

Figure 8 shows the functioning of the Albufera of Valencia based on a phosphorus balance. Phosphorus enters the Albufera in soluble inorganic form or as particles of organic matter with a low proportion of algal cells and leaves it mainly in form of phytoplankton biomass. Aquarium experiments using Albufera water and mud demonstrated that dissolved phosphorus added to the water remains there, the rate of deposition in the sediments being extremely low. However, particulate phosphorus may be deposited in the sediment as not recycled organic matter. On the other hand, 100 times more biomass leaves the system than enters it. This is because the lagoon



B.	**Biomass, fresh weight**
O.M.	**Organic matter, fresh weight**
O-P	**Dissolved Phosphorous**
P-P	**Particulated Phosphorous**
C	**Organic carbon**

Lagoon volume 27 Hm^3
Lagoon surface 23 Km^2

Water and sediemnt contents in id kg
The rest of values are rates in 10^3 kg yr^{-1}

Figure 8. Model of functioning of the Albufera of Valencia

acts as a continuous culture: primary production develops in equal parts from external nutrient input and from recycling of previous phytoplanktonic production. From this assumption and taking into account the relationship P/biomass = 1/500, it is estimated that the phytoplankton uses about half of the total P input (which was around 10^6 kg yr^{-1}). If soluble inorganic P is maintained in the water, then about 500x103 kg of the allochthonous particulate P must have gone to the sediment that year, together with 300x10^3 kg of particulate P derived from the 150x106 kg yr^{-1} of organic matter from autochthonous not recycled primary production. Summarizing, half of the primary production is recycled and reincorporated to enhance new production while the other half is exported: 20 % to the sea and 30 % to the sediment. Primary production is too low when compared with P input and the standing crop of algal biomass in the lake. The system is limited by light, yielding a production of around 2 g C m^{-3} h^{-1} (corresponding to 4 mg C/mg chlorophyll) restricted to a thin surface layer, being negligible in the rest of the water profile. Thus, daily primary production is about 4 g C m^{-2} on a year-round average. Evidently it varies seasonally as will be described in the next section. Yet the theoretical annual average of 4 g C m^{-2}d^{-1} based on P balance is very close to the actual value obtained experimentally by using the ^{14}C method (see next section and table 2).

In conclusion, the Albufera functions both as a chemostat and a sewage treatment pool. Great amounts of nutrients and organic matter enter the lagoon, whose outflow is almost free of the limiting nutrients (phosphorus and nitrogen). Within the lagoon, however, nutrients and organic matter are converted into biomass which is mostly removed from the system into the sediment, a small fraction being exported through the outflows to the sea.

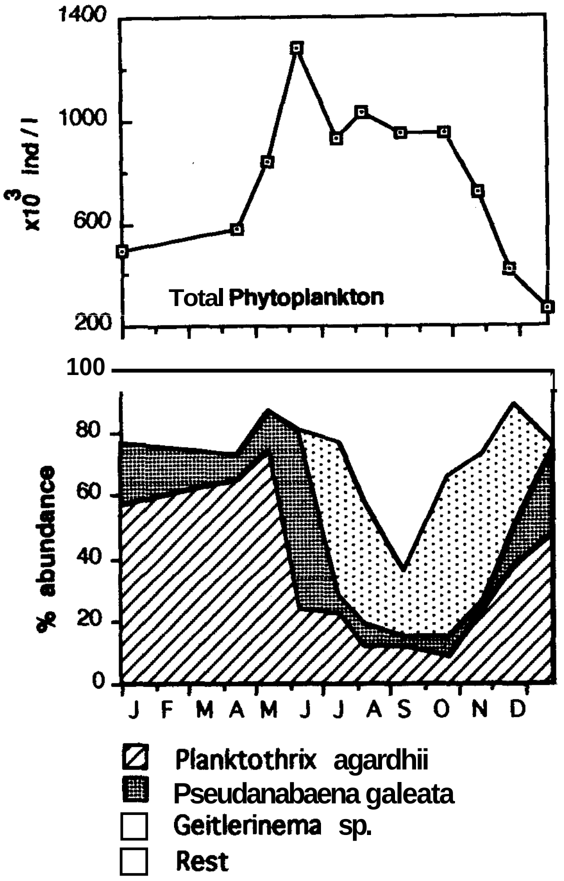


Figure 9. Total phytoplankton abundance and annual succession of the three main phytoplankton species during the year 1986. Top: Total number of phytoplankton individuals. Bottom: Relative abundance of the three main species with respect to total phytoplankton. The diminishing of their relative abundance in summer was mainly a result of an important increment of *Planktolyngbya contorta* (from data of ROMO, 1991).

Phytoplankton

The lagoon is densely populated by cyanobacteria and heterotrophic bacteria which form continuous blooms throughout the year. However, phytoplankton is dominated by chlorophyceae and euglerophyceae in the organic matter-rich northern channels. In the southern channels diatoms dominate in early spring, but dominance is shifted to chlorophyceae in late spring-summer. In channels with an important flow and water supply from underground springs phytoplankton mainly consists of diatoms.

Table 2. Planktonic primary production in the Albufera of Valencia during an annual cycle (1980-81)

	June	July	Aug	Sept	Nov	Jan	Apr	May
% cyanobacteria	58	93	98	87	74	77	41	82
Chlorophyll a	396	375	509	221	252	418	691	834
PP* mg C m^{-3}h^{-1}	1780	1010	1006	386	510	418	524	697
% DOC/PP		7.2	13.0	10.6	7.0	18.1	13.7	16.4
PP/Chl *a*	4.5	2.7	2.0	1.7	2.0	1.0	0.8	0.8

* PP is the sum of POC+DOC

Table 3. Main phytoplankton species during 1980-88, indicating their frequency (Fr) with respect to the total number of individual~their occurrence (Occ) as % with respect to the total number of samples, and mean density when present (ind/ml). Modified from ROMO (1991).

Species	Fr	Occ	Mean
Cyanophyta			
Planktothrix agardhii	3	99	39363
Pseudanabaena galeata	3	96	41430
Geitlerinema sp.	3	77	70173
Anabaenopsis elenkinii	2	75	4233
Planktolyngbya subtilis	2	59	75253
Planktolyngbya contorta	2	72	18383
Jaaginema cf. metaphyticum	2	50	13500
Geitlerinema amphihium	1	44	7580
Cylindrospermopsis raciborskii	1	18	10597
Aphanothece clathrata	1	30	16050
Microcystis flos-aquae	1	23	1793
Merismopedia tenuissima	1	66	2630
Oscillatoria lanceaeformis	1	45	5053
Cholorophyta			
Microcystis incerta	1	29	2487
Monoraphidium griffithii	1	39	640
Monoraphidium contortum	1	90	1430
Monoraphidium minutun	1	67	417
Tetraedrom minimum	1	64	330
Actinastrum hantzschii	1	77	647
Chlamydomonas sp	1	69	1593
Scenedesmus quadricauda	1	84	723
Scenedesmus acuminatus	1	97	1587
Scenedesmus acutus	1	63	506
Scenedesmus obliquus	1	46	720
Closteriopsis acicularis	1	49	440
Chlorella vulgaris	1	18	1220
Dyctiosphaerium pulchellum	1	53	610
Coelastrum microporum	1	38	530
Choricystis minor	1	35	1200
Bacillariophyceae			
Cyclotella meneghinianu	2	99	4110
Cyclotella glomerata	1	91	3070
Nitzschia palea	1	89	2200
Nitzschia intermedia	1	66	600
Nitzschia longissima	1	63	860
Nitzschia gracilis	1	70	1480
Nitzschia acicularis	1	50	600
Euglenophyceae			
Trachelomonas cf. volvocina	1	28	480
Cryptophyceae			
Cryptomonas erosa	1	86	930
Rhodomonus lacustris	1	83	1720

Freyuency values: **3** >10% **2** 10 - 1% 1 1 - 0,1%

The phytoplankton density in the Albufera lagoon is 10^5 to 10^6 ind ml^{-1}, which corresponds to a biomass of 60-400 mg l^{-1} and chlorophyll concentrations of 200-600 $\mu g\ l^{-1}$, with minima during the periods of high water turnover rates (when sluicegates are opened) and maxima during the periods of stagnancy, with generally higher values in spring-summer due to the mentioned cycle in rice cultivation.

Studies on phytoplankton are only very recent (GARCIA *et al.*, 1984; MIRACLE *et al.*, 1984a, 1987; SORIA *et al.*, 1987b; ROMO, 1991; ROMO & MIRACLE, *in press).* However, short lists of the principal phytoplankton species obtained from occasional net samples are presented in PARDO (1942) and BLANCO (1974), confirming the dramatic phytoplankton changes caused by the eutrophication process. Phytoplankton has been shifting from a community dominated by diatoms and chlorophyceae (PARDO, 1942) to a eutrophic lake community still dominated by chlorophyceae (BLANCO, 1974) and on to the hypertrophic community of present times, absolutely dominated by filamentous cyanobacteria (plate 1, table 2). In the period of 1980-88 (ROMO, 1991), three dominant species accounted for more than 50 % of the total phytoplankton throughout the year, summing more than 75 % in many occasions: *Planktothrix agardhii, Pseudanubaena galeata* and *Geitlerinema* sp. They are virtually permanent in the plankton yet alternatively dominant according to the seasonal cycle. *Planktothrix agardhii* (formerly *Oscillatoria agardhii,* filament diameter ca. 8 µm), which primarily exhibited dominance throughout the winter plankton and during the last years (1986-88), is a large vacuolar oscillatorial blooming in early spring. This alga occasionally may produce floating accumulations distributed by wind action and water circulation. *Pseudanuhaena galeata* and *Geitlerinema* sp.(defined as Oscillatoria of the *redekei* group in our previous studies) are very thin oscillatorial species (filament diameter ca. 1-2 µm) (table 3).

These three species manifest a distinct annual succession (fig. 9). During the last years, a peak of *P. agardhii* appea-

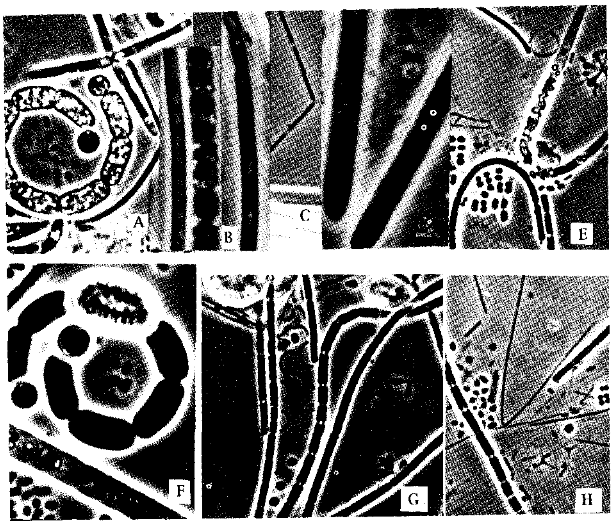


Plate 1. Microphotograph of Albufera of Valencia water samples (spring-summer 1985-86). A) *Anabaenopsis circularis* (vacuolated cyanobacteria with terminal heterocysts), B) *Pseudanabaena galeata* and *Planktothrix agardhii*, C) *Haliscomenobacter*, *D) Planktothrix agardhii*, *E) Merismopedia*, *P. galeata* and *Blastocaulis-Planctomyces*, F) *A. circularis* with acinetum, *P. agardhii* and *Aphanothece clathrata*, G) *Microcyclus*, *P. galeata*, *Blastocaulis-Planctomyces*, H) *Ancalomicrobium*, *Haliscomenobacter*, *P. galeata*.

red when the sluicegates were closed in April, followed by a peak of P. *galeata* and then by a total dominance of *Geitlerinema* throughout the summer, sometimes accompanied by other filamentous cyanobacteria such as *Lyngbya* spp (e.g. *Lynghya contorna* and *Lyngbya subtilis*) and also by the characteristic tropical species *Anabaenopsis circular-is*, a recent colonizer (plate 1). In the autumn stagnancy period dominance of P. *galeata* was most common although the other two main species were also present. None of the just mentioned species had been cited before by PARDO (1942) or BLANCO (1974). Other phytoplankton groups are very scarce, chlorophyceae being second in importance with a maximum representation in spring, and diatoms (mainly *Cyclotella* and *Nitzchia)* seldom occurring and only with some incidence in late winter-early spring.

The growth of these cyanobacteria promotes a high primary production throughout the year, though restricted to the surface. The results of primary production diel experiments using the ^{14}C and oxygen methods, carried out during the annual cycle of 1980-81, are shown in table 2. The integrated production in the water column varied from 2 g C $m^{-2}d^{-1}$ in winter to 7 g C $m^{-2}d^{-1}$ in spring. Dark assimilation (DA) was also very high and fluctuated accordingly with a late spring maximum of 3 g C $m^{-2}d^{-1}$ (ca. 34 % of primary production) and a winter minimum of 0.2 g C $m^{-2}d^{-1}$ (ca. 11 % of the primary production). The vertical distribution of primary production and dark assimilation during a diel cycle (30 May, 1980) is illustrated in fig. 10. The alternative maxima of primary production (day at surface) and dark assimilation (night and day at bottom) are evident. ^{14}C production experiments were repeated in October 1988, yielding a high production for this time of the year, i.e., 1.3 g C $m^{-3}h^{-1}$ at the surface, 0.07 g C $m^{-3}h^{-1}$ at 0.3 m and not detectable at 1 m of depth (measures taken in the afternoon).

Bacteria

Important populations of heterotrophic bacteria develop in the Albufera water due to its high content of dissolved organic compounds (DOC), produce of algal excretions and allochthonous contributions. Other bacteria owe their presence to pollution of the lagoon with sewage water (*Escherichia coli*, *Streptococcus*, *Salmonella*, *Vibrio*, etc.), studied by ALCAIDE *et al.* (1982); ALCAIDE & GARAY

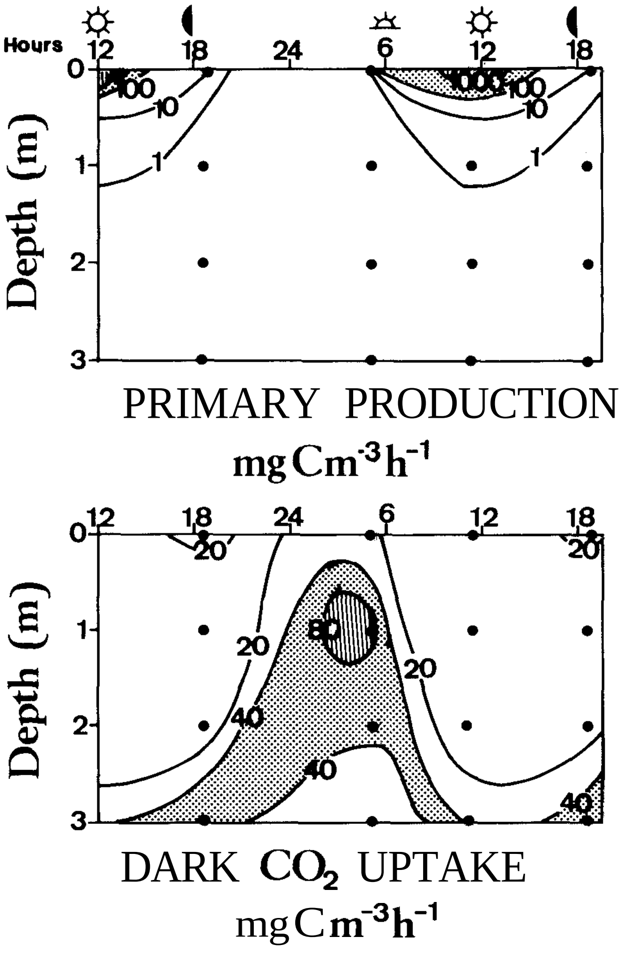


Figure 10. Diel cycle of primary production and CO_2 dark assimilation (experiments performed on May 29-30, 1980).

Table 4. Zooplankton species found in the Albufera of Valencia (1) in 1916-18 (AREVALO, 1916, 1918), (2) in 1929 (WISZNIEWSKI, 1931), (3) in 1973 (BLANCO, 1974), (4) in 1980-82 (OLTRA & MIRACLE, 1984, 1992) and (5) in 1985-88 (ALFONSO & MIRACLE, 1990).

	1	2	3	4	5		1	2	3	4	5
COPEPODA											
Paracyclops fimbriatus			!	—		*Lepadella rhomboides*	—	—	—	○	—
Macrocyclops albidus				—		*Colurella uncinata*	○	○	—	—	○
Halucyclops sp			-	—		*Colurella adriatica*	—	○	○	○	—
Acanthocyclops robustus			—	●	●	*Lecane luna*	●	○	○	○	○
CLADOCERA						*Lecane lunaris*	○	○	○	○	○
Ceriodaphnia laticaudata			—	—		*Lecane bulla*	○	○	○	○	○
Iliocryptus sordidus			—	—		*Lecane quadridentata*	●	○	○	—	○
Macrothrix hirsuticornis			—	—	—	*Lecane signifera*	○	—	—	—	—
Alona guttata	○		—	—	—	*Lecane ohionenesis*	●	○	—	—	—
Alonella exigua	○		—	—	—	*Lecane papuana*	—	○	○	—	○
Pleuroxus aduncus			—	—	—	*Lecane ungulata*	—	○	—	—	○
Chydorus sphaericus			—	—	—	*Lecane crepida*	—	○	—	—	—
Simocephalus vetulus				—		*Lecane hornemanii*	—	○	—	—	—
Alona rectangula			—	*e*		*L. inopinata f. sympoda*	—	○	—	—	—
Bosmina longirostris	—			—		*Lecane stichaea*	—	○	—	—	—
Daphnia pulex	—		**e**	—		*~~L~~ecane lamellata thalera*	—	○	—	—	—
Daphnia magna	—		**e**			*Lecane stenroosi*	—	○	—	○	—
Leydigia quadrangularis	—				—	*Lecane obtusa*	—	○	—	—	—
Moina micrura	—					*Lecane punctata*	—	○	—	—	—
Moina macrocopa	—		—	○	○	*Lecane arcuata*	—	○	—	—	—
ROTIFERA						*Lecane closterocerca*	—	○	—	●	○
Brachionus urceolaris	●	○	○	○	○	*Lecane hamata*	—	○	—	○	○
Brachionus quadridentatus	●	○	○	●	○	*Lecane aculeata*	—	○	—	○	—
Brachionus calyciflorus	●	—	●	●	●	*Lecane furcata*	—	○	—	○	—
Brachionus angularis		—	●	●	●	*Lecane tenuiseta*	—	—	—	○	—
Brachionus polyacanthus		○	○	—	—	*Monommata grandis*	—	○	—	—	—
Brachionus leydigi		—	—	●	○	*Cephalodella gibba*	—	—	○	○	○
Brachionus bidentata	—	—	—	○	○	*Trichocerca pusilla*	○	—	—	—	—
Brachionus plicatilis	—	—	—	○	○	*Trichocerca cylindrica*	○	—	—	—	—
Keratella quadrata	●	○	●	○	○	*Trichocerca longiseta*	●	—	—	—	—
Keratella cochlearis	—	○	●	○	○	*Trichocerca rattus*	—	○	○	—	—
Keratella valga	—	—	●	—	—	*Trichocerca tenuior*	—	○	—	—	—
Keratella tropica	—	—	○	○	○	*Synchaeta pectinata*	○	—	●	—	○
Notholca acuminata	●	—	○	○	○	*Synchaeta oblonga*	—	—	—	●	●
Notholca salina	—	—	—	○	—	*Polyarthra spp*	○	○	●	●	●
Anuraeopsis fissa	●	○	●	○	○	*Asplanchna brightwelli*	—	—	●	—	○
Euchlanis dilatata	—	○	—	—	○	*Asplanchna girodi*	—	—	—	●	○
Tripleuchlanis plicata	—	○	—	—	○	*Testudinella patina*	○	○	○	—	○
Mytilina ventralis	—	○	○	○	○	*Conochilus unicornis*	—	—	○	—	○
Lophocharis oxysternon	—	○	—	—	○	*Hexarhra mira*	○	—	—	—	—
Lophocharis salpina	—		—		—	*Hexarthra fennica*	—	○	—	—	○
Trichotria pocillum	/			—	—	*Hexarthra oxyuris*	—	○	—	—	—
Macrochaetus altamirai			—	—	—	*Filinia terminalis*	●	—	●	○	—
Lepadella ehrenbergi	●		—	—	—	*Dissotrocha aculeata*	—	○	○	—	—
Lepadella ovalis	—		—	—		*Rotaria rotatoria*	—	—	○	—	—
Lepadella patella	—		—			*Rotaria neptunia*	—	—	○	—	○

— absent, present, / abundant. Modified from OLTRA & MIRACLE (1992).

(1984) MIRACLE *et al.* 1984b. Populations of planktonic heterotrophic bacteria not resulting from pollution are also important in the lagoon. Among these there are to be found: 1) gliding bacteria of the genera *Fexibacter, Herpethosyphon, Achroonema* and *Beggiatoa, 2)* sheathed bacteria of the genus *Haliscomenobacter*, present in this lagoon because of their affinity to aquatic media with a high content of organic matter, 3) prosthecated and/or budding or appendaged bacteria of the genera *Ancalomicrobium, Blastocaulis-Planctomyces, Phylomicrobium* and *Pasteuria*, 4) besides these generally infrequent forms, numerous flexuous bacteria of the genus *Spirochaeta*, and 5) spiral and curved bacteria such as *Spirillum* and various species of the genera *Microcyclus* and *Brachyarcus* (Plate 1) (VICENTE & MIRACLE, 1988).

Zooplankton

At present, the zooplankton of the Albufera is constituted basically by two dominant species: the copepod *Acanthocyclops robustus* and the rotifer *Brachionus angularis*. Recent publications (OLTRA & MIRACLE, 1984, 1992; MIRACLE *et al.*, 1988; ALFONSO & MIRACLE. 1990) show the distribution of zooplankton populations in different zones of the lagoon at different times of the year for the years 1980-88. From the quantitative analyses presented in these works it can be deduced that: (1) the zooplanktonic biomass of this lagoon is very high, on an average about 2 mg l^{-1}, corresponding roughly to 2 individuals/ml, and (2) the ratio of zooplankton to phytoplankton biomass is very low, of the order of 1:100; if the numbers of individuals are considered, the zooplankton/phytoplankton ratio oscillates around 2:1,000,000. Both results are characteristic features of hypertrophic lagoons dominated by filamentous cyanobacteria, which are not appropriate food for most zooplankton species.

The statistical study of Albufera zooplankton, from different sites and times of the year, during the annual cycle of 1982 (OLTRA & MIRACLE, 1984) points out the existence of several main associations or groups of species corresponding to seasonal succession: (a) a group constituted by the permanent species *Acanthocyclops vernalis* and the almost permanent *Brachionus angularis*, (b) a second group, occurring at the end of summer, composed of *Brachionus calyciflorus, Anuraeopsis fissa, Asplanchna girodi* and *Moina* spp., and (c) a third group, occurring in autumn-winter, formed by *Brachionus leydigi, Synchaeta tremula* and *Polyarthra longiremis*. The importance of these groups varies greatly at the different sampling sites. Those corresponding to the northern margin of the lagoon show a predominance of rotifers over copepods and a much more marked succession in time than the rest. Furthermore, the sites stronger influenced by channel or brook flows are notably characterized, towards the end of summer, by the abovementioned second group of species with a dominance of *B. calyciflorus*, which is almost inexistent in the rest of the lagoon. The same has been observed during the four annual cycles from 1985 to 1988 (ALFONSO & MIRACLE, 1990).

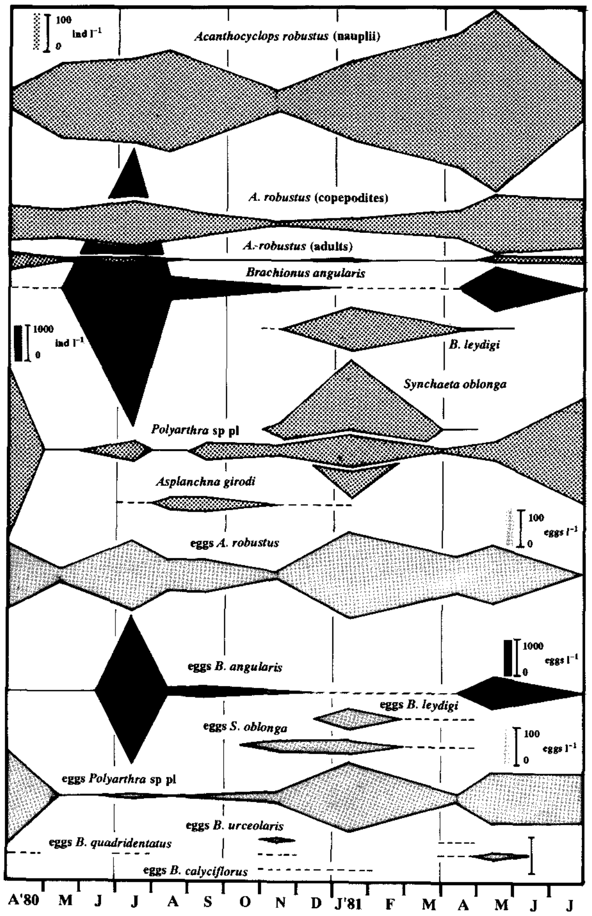


Figure 11. Annual cycle of the main zooplankton species during 1980-81. Densities (means of samples taken in vertical profiles at different hours) are represented by the width of the graphs according to the respective scales. ... < 1 ind. or egg per litre; —- 1-10 ind. or eggs per litre (from OLTRA & MIRACLE, 1992).

Comparison of these recent studies with former publications on Albufera zooplankton makes evident that a dramatic change in species composition has taken place. The present dominant species, A. *robustus* and *B. angularis*, were very rare at the beginning of the century (AREVALO, 1916, 1918; WISZNIEWSKI, 1931), while species recorded then as the most abundant - such as *Keratella quadrata, Filinia terminalis, Anuraeopsis fissa, Trichocerca longiseta, Ceriodaphnia laticaudata* and *Simocephalus vetulus* - have disappeared or are much reduced (table 4).

In the quantitative study realized by BLANCO (1974, 1981), which corresponds to the years 1972-73, an important population of B. *calyciflorus* is distinguished in spring, attaining 450 ind l^{-1} in May, while K. *quadrata* is most outstanding in late summer and early autumn (1000 ind l^{-1}) and F. *terminalis* in winter and early spring (350 ind l^{-1}). With regard to the species most abundant at present, Blanco only mentions that B. *angularis* and *Polyarthra* spp exhibit very low population densities with certain peaks (about 200 ind l^{-1}) strictly limited to some periods of the year. Blanco also describes a succession of cladoceran species, all of which have now almost disappeared.

The comparison of these 1972-73 data with the annual zooplankton cycle in 1980-81 (fig. 11) confirms the drastic changes the lagoon has been suffering in recent years.

FINAL COMMENTS

The Albufera of Valencia, a shallow coastal lagoon surrounded by marshlands and formerly a complex ecosystem with a high biomass and species diversity, has been converted into "the great purification pool" of all the sewage waters of its watershed. At present, water enters the Albufera with high levels of nutrients and leaves it nutrient free, although laden with cyanobacterial biomass. This phenomenon is illustrated in figs. 5 and 8.

Shallowness, turbulence and bioturbidity favour heterotrophic metabolism in the water. The system is so stressed that nutrients and dissolved organic matter, released from the dying cells themselves, can short-cut and be used again immediately by the permanent bloom of autotrophic and mixotrophic organisms.

More than a quarter of this algal biomass, however, will not recycle but deposit as sediments and nearly another quarter will be transferred to the sea. Planktonic trophic chains have been much reduced and benthonic and littoral-benthonic communities greatly simplified. Biodiversity then has been strongly reduced, which is easily visualized in the higher organisms such as macrophytes and vertebrates. After years without apparent changes, catastrophic shifts occurred. Around the end of the sixties and beginning of the seventies the submersed macrophyte prairies vanished and planktonic communities drastically changed. Thus, the system now functions on an autotrophic (and mixotrophic) cyanobacteria and heterotrophic bacteria basis. Overcast after sunny periods, temperature changes or other factors could easily cause massive algal die-off and the delicate balance between production and respiration could be reversed producing a dystrophic crisis.

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