Verh. Internat. Verein. Limnol.	28	564–568	Stuttgart, July 2002

Relations between physico–chemical and biological variables in aquatic ecosystems of the Albufera Natural Park (Valencia, Spain)

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Introduction

The Natural Park of the Albufera is a territory of 211.2 km^2 located in the east of the Iberian Peninsula, next to the Mediterranean Sea, among the outlets of the Rivers Turia and Júcar. Rice fields occupy the primitive marshland, with only a few hectares still in their natural state. The Albufera of Valencia lagoon is located in the centre of the Natural Park. It is almost circular in form and is approximately 8 km in diameter, with an area of 23.94 km^2 (Sanjaume et al. 1992), and a mean depth of 1 m. Three channels connect the Albufera with the sea, where outflow is regulated by floodgates that maintain water levels in the rice field. Almost 450,000 people live in the region to the north and west of the humid area. There are numerous industries in the area, from which partially purified effluent waters flow into natural channels belonging to the hydrographic basin of the Albufera. Figure 1 shows the location of the study area, indicating the sampling points. Water inflows arrive in numerous channels from the Rivers Turia and Júcar and from several ravines, some containing sewage from the local populations, and from abundant existent springs. These factors determine the characteristics of the water body, and differentiate it from other natural coastal aquatic ecosystems that are not subjected to strong human influences, and in which the cycles fluctuate naturally with the time of year and climatic variations without the interference that the Albufera suffers.

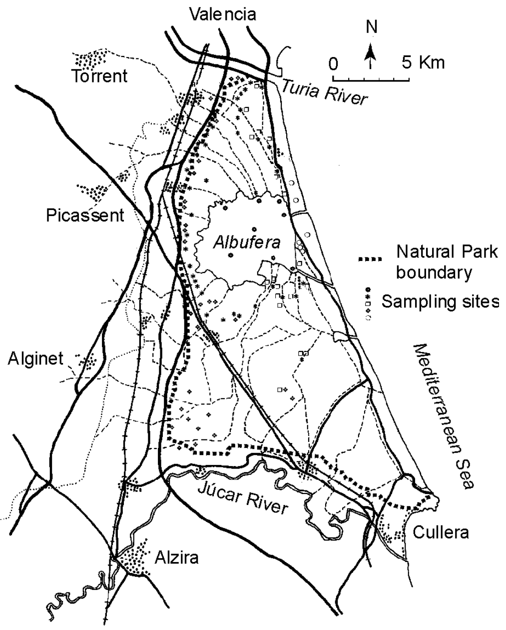

Fig. 1. Approximate locations of the sampling points on the outline of the Albufera Natural Park, indicating main rivers, cities, the boundary of the Park, roads and railways (solid lines) and irrigation channels (dashed lines).

Limnological studies on the Albufera began in 1980. The heterogeneity of Albufera was described in Serra et al. (1984) and Oltra & Miracle (1992) and the physico–chemical characteristics in Miracle et al. (1987). From 1985 to 1988, the main objectives were the study of the limnology and eutrophication of the whole marshland, including the Albufera, channels, rice fields, springs (known as 'ullals'), as well as the intradune lagoons of the Devesa (known as 'malladas'). At the same time, studies on the phytoplankton, zooplankton and primary production were carried out. Different aspects of these results have been published in diverse scientific publications (Soria et al. 1987, Alfonso & Miracle 1987, 1990, Romo & Miracle 1994, Romo & Van Tongeren 1995, Soria & Alfonso 1993), and a synthesis was published by Vicente & Miracle (1992).

Methods

From February 1985 to December 1988, 654 sam-

0368-0770/02/0028-0564 $ 1.25

ples were taken in various central and perimetral sites of the Albufera and in diverse channels, ravines, rice fields, springs and intradune lagoons, following the methodology of Golterman et al. (1978). Parameters studied in this analysis are indicated in Table 1, grouped according to their origin: Albufera, channels and rice fields (divided into north and south), and springs and intradune lagoons. The relationships between the physico–chemical and biological variables have been explored with principal component analysis (PCA) using the statistical program SPSS. The analysis was carried out using the correlation matrix between variables which had been normalised with the appropriate transformations (Legendre & Legendre 1979).

Results

Conductivity in the temporary series of the Albufera and the intradune lagoons increased during the periods of intense evaporation, and declined in the rainy season due to the dilution of the water (Soria et al. 2000). Chlorophyll *a* followed a similar variation (Table 1). Conductivity declined in the rice fields during the cultivation period, while during the winter flood the tendency was to increase toward the end of the flood period. In the channels, the values were variable, while in the springs they were more constant. All of the waters studied exhibit a sulphate–chloride dominance. The intradune lagoons had a greater dominance of chloride. Fertilisers from the adjacent agricultural areas resulted in nitrate enrichment. These values are very high in the springs, and the water is heavily polluted. This is the case for all the underground waters of the area, making them unsuitable for drinking water. However, in the northern area, the dominant compound is ammonium, due to sewage. The concentration of ammonium in the water in the rice fields is low due to denitrification processes in the sediment. There were high concentrations of ammonium in the channels of the North, which receive more residual waters, as well as in the adjacent rice fields.

The concentration of soluble phosphate is low in the Albufera, because it is assimilated by the biomass, or it precipitates to the sediment, combining with calcium to form apatite, and contributes to the decrease in alkalinity in the Albufera. The intradune lagoons and the springs have low concentrations due to the absence of the influence of organic matter.

There were very high levels of chlorophyll *a* in the Albufera, especially in the rice fields of the northern area. The lowest averages were in the channels, intradune lagoons and springs.

Table 1. Mean and standard deviation of the studied variables in each ecosystem.

Variable	Albufera	N Channels	S Channels	N Rice fields	S Rice fields	Springs	Intradune lagoons
Temperature °C	18.8 ± 7	19.8 ± 6	18.8 ± 6	21.1 ± 8	19.7 ± 9	20.0 ± 2	18.4 ± 7
Conductivity µS cm^{-1}	1948.8 ± 591	2155.8 ± 828	1542.1 ± 340	2749.8 ± 942	1533.0 ± 469	1793.1 ± 594	13995.3 ± 18004
Oxygen mg L^{-1}	12.5 ± 4	4.6 ± 5	7.5 ± 4	11.0 ± 8	11.6 ± 5	7.3 ± 2	7.5 ± 5
pH	8.8 ± 1	7.9 ± 1	7.9 ± 0	8.3 ± 1	8.2 ± 1	7.5 ± 0	8.0 ± 1
Eh mV	349.0 ± 59	218.6 ± 132	334.2 ± 76	251.5 ± 66	336.2 ± 45	338.8 ± 74	371.4 ± 65
Alkalinity mg L^{-1}	2.4 ± 1	5.6 ± 2	3.8 ± 1	5.0 ± 2	3.3 ± 1	4.2 ± 1	6.1 ± 3
Chloride meq L^{-1}	11.3 ± 5	12.6 ± 15	7.4 ± 5	14.9 ± 9	6.1 ± 3	7.1 ± 7	219.2 ± 323
Sulphate meq L^{-1}	9.3 ± 3	12.4 ± 6	9.1 ± 4	11.2 ± 4	7.1 ± 3	7.0 ± 2	21.0 ± 29
Nitrate mM L^{-1}	62.8 ± 143	238.3 ± 312	305.4 ± 322	25.8 ± 59	91.7 ± 285	1673.5 ± 1180	3.4 ± 9
Nitrite mM L^{-1}	4.9 ± 6	49.7 ± 84	15.8 ± 25	10.3 ± 25	2.7 ± 4	3.5 ± 10	0.3 ± 0
Ammonium mM L^{-1}	39.6 ± 98	796.3 ± 891	168.2 ± 594	225.7 ± 383	9.4 ± 23	14.6 ± 69	19.0 ± 46
Phosphate mM L^{-1}	2.9 ± 9	78.9 ± 69	7.6 ± 20	48.3 ± 68	0.8 ± 2	0.3 ± 1	0.7 ± 2
Silicate mM L^{-1}	90.5 ± 60	166.9 ± 82	112.7 ± 81	129.9 ± 111	118.6 ± 109	151.8 ± 57	150.4 ± 128
Chlorophyll *a* µg L^{-1}	322.3 ± 166	73.4 ± 153	29.0 ± 66	190.6 ± 242	45.7 ± 54	3.5 ± 12	31.9 ± 24

Discussion

Multivariate analysis

The data obtained for each variable, and used to characterise the aquatic ecosystems of the Albufera Natural Park, were processed jointly to evaluate interrelations between different physico–chemical and biological parameters and to characterise the different sites by means of multivariate analysis. The correlation matrix is represented by the cluster in Fig. 2. The correlation was high among the mineralisation parameters. The conductivity was highly correlated with the concentration of chloride (r = 0.886; P < 0.01) and less so with the sulphate (r = 0.606; P < 0.05). Alkalinity was not correlated with mineralisation because it was heavily influenced by the biological processes and primary production, although it was positively correlated with ammonium (r = 0.443) and with phosphate (r = 0.499), and negatively with chlorophyll *a* concentration; these values are not significant (P > 0.05).

Other highly correlated parameters were those that were associated with a high algal production, including chlorophyll, pH and oxygen, or inversely correlated, such as the alkalinity. The correlation coefficient between pH and chlorophyll was r = 0.564 (P < 0.05). Alkalinity and pH were negatively correlated r = –0.607 (P < 0.05). Because photosynthetic activity displaces the carbonic–carbonate dissociation, precipitation of calcium carbonate is favoured and the alkalinity decreases with increasing pH. The mean value of pH for the Albufera was 8.82 and for the springs was 7.45. These values are in accord with the low alkalinity, eutrophication and algal biomass of the Albufera, and with lower alkalinity, eutrophy, and algal density in the springs.

The alkalinity and the oxygen were also negatively correlated (P < 0.05, r = –0.531). The low values of alkalinity coincided with very high values of dissolved oxygen in the waters, mainly the eutrophic systems like the Albufera and some channels of the northern area. The positive correlation between the ammonium and the nitrite (r = 0.524; P < 0.05) may be related to the existence of both compounds at the same time, with nitrite being a transition element that occurred mainly in the reducing sites, during the initial processes of the nitrification.

Finally, the positive correlation of chlorophyll with pH (r = 0.612; P < 0.05) and the negative correlation with nitrate (r = –0.538; P < 0.05) probably arise from two totally different relationships. While the former results from photosynthetic activity, where the decline in alkalinity favours the increase of pH, the latter simply arises among sites with smaller chlorophyll concentrations of lower trophic state which coincide with the springs that are polluted with nitrates.

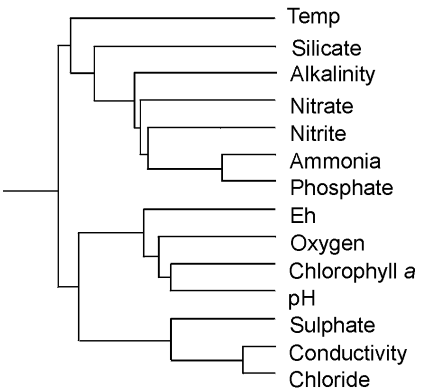

Fig. 2. Cluster of the matrix correlation between the studied variables.

Principal components analysis

Principal component analysis has been used to study the interactions of all the parameters in a combined manner. The results of the PCA indicate that the first three components accounted for 59% of the variation. In a factorial analysis, the first two factors of the PCA explained 48% of the total variance in the space of the principal components. The first factor explained 28% of the variance; it separated the non-productive waters, which were loaded with nutrients, from the subsystems of high primary production, where the nutrients had been incorporated into the biomass. This process can be associated with the level of contamination characteristic of the channels affected by sewage waters (northern area) and those influenced by the agricultural contamination of the southern area. The positive parameters define the waters of the Albufera, non-polluted rice fields and to a lesser degree the springs and intradune lagoons (Fig. 3).

The negative part can be associated with well-oxygenated waters, and can be related to high values of chlorophyll *a* and pH. This is partly due to photosynthetic activity, which produces an increase in the pH and a decrease in alkalinity favouring the precipitation of carbonate. Nutrients were present in low concentrations since they were probably incorporated by the phytoplankton, especially in the Albufera and rice fields of the South or under the influence of the lagoon.

The second factor (Fig. 3) explained 20% of the variance, separating the variables and the samples associated with mineralisation of the water. In the positive field variables such as conductivity, chloride and sulphate were related to the mineralisation of the water. In the negative field nitrate, nitrite and oxygen were dominant. Therefore, the positive part correlates with the sites with mineralised water, such as the brackish intradune lagoons and some channels of the northern area. The springs, non-brackish rice fields, and those samples of the Albufera with lower mineralisation but higher concentrations of nitrates, are on the other side. Other variables, such as chlorophyll *a*, pH and oxygen, are located in the area of low correlation with regard to this factor, i.e. the areas of the lagoon more influenced by the water inflow from the agricultural channels.

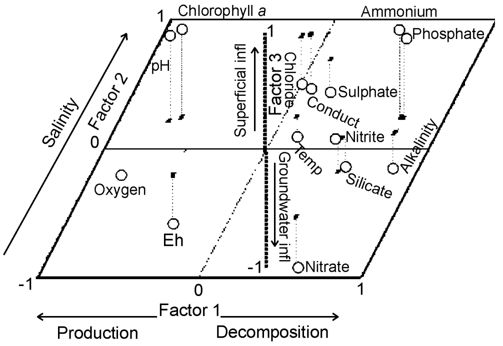

Fig. 3. Representation of the coefficient of correlation of the physico–chemical variables in the space defined by the principal components Factor 1 in front of Factor 2 and Factor 3.

The third factor explained 11% of the variance of the data (Fig. 3), determined in the positive part by phosphate, nitrite, ammonium and also by chlorophyll *a* and the pH. These variables characterised the areas under the influence of the contamination of the system, where the mineralisation characteristic of the system is impacted by nitrates in areas of intensive agriculture. In the negative field, they are the bound variables associated with mineralisation of the water and the nitrates. This factor, although masked by the different characteristics, corresponds to the channels and points of the Albufera that are directly polluted by sewage. While Factor 1 relates the chlorophyll with the primary production, in waters with very low nutrient content because these have been incorporated by the high phytoplankton population, Factor 3 is concerned with the nutrients, especially with those that come from sewage before they are incorporated in the system when it is loaded by phreatic waters poor in phosphorus, but very rich in nitrates.

Conclusions

PCA can assign, to each one of the components, their influence in the aquatic system. The first component defines the contamination of the systems in front of the primary production. The second component defines the mineralisation of the waters. The third evaluates sites contaminated especially by sewage channels in front of the clean sites or sites only contaminated by nitrates.

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