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The influence of flash floods on the limnology of the Albufera of Valencia lagoon (Spain)

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Introduction

The Albufera is a hypertrophic oligohaline lagoon, with a mean chlorophyll *a* concentration of about 322 mg m^{-3}, and a conductivity of 1949 μS cm^{-1} (SORIA 1997). Until now, we thought that the most important factor explaining the variation in the limnology of the Albufera was the disposal of drainage and surplus irrigation waters in the rice fields (MIRACLE et al. 1987, VICENTE & MIRACLE 1992). However, the results obtained in this 4-year survey indicate that the main reason for variation is the inflows after heavy showers. The thermal inertia that keeps the Mediterranean Sea warm in autumn, and the input of cold air in the upper layers of the atmosphere cause heavy showers (>100 mm day^{-1}) and floods. Sometimes, a single storm could double the annual mean rainfall. Furthermore, the storm may last only a few hours and the infiltration potential of soil is low whereas runoff increases (CAMARASA 1995). Only 2 h after the initial rain, the so-called flash flood begins.

Site description

The Albufera of Valencia is a shallow coastal lagoon (mean depth 1 m) situated on the Mediterranean coast, south of Valencia. The lagoon area is 23.2 km^2, and is surrounded by 223 km^2 of rice fields. The whole of the Albufera and rice fields were designated as a Natural Park in 1986. The hydrographic basin has an area of 917.1 km^2, ranging from sea level to an altitude of 1100 m a.s.l. and it drains into the Albufera via gullies: the main ones are the Poyo Gully (also known as Torrent Gully or Massanassa Gully), which is the main channel, of which the catchment area is 367.6 km^2 (40% of the basin), and the Beniparrell Gully (also known as Picassent Gully). The other gullies end in ditches in the orchards and rice fields that flow into the Albufera. Although the Albufera has a defined hydrological basin, it only contributes a minor proportion of the inflow. Most of the water comes from the Júcar River by the Acequia Real del Jucar (Royal Channel of the Júcar River) or by the Sueca and Cullera irrigation channels (Fig. 1). Therefore, the Albufera forms part of the hydrologic system of the Júcar River, because it also receives the runoff from the rice fields via 63 channels and ditches. Some of these channels also carry a portion of the sewage of towns near the Albufera. The Albufera is also supplied with spring water from the bottom of the lagoon and between the fields (known as ullals), whose waters enter the network pattern of ditches that cross the fields. Finally, the average rainfall in the area is 600 mm $year^{-1}$.

In summary, the water discharge to the Albufera in an ordinary year is:

Running drain water:	40×10^6 m^3 $year^{-1}$
Drain groundwater:	40×10^6 m^3 $year^{-1}$
Sewage:	80×10^6 m^3 $year^{-1}$
Rice fields runoff:	120×10^6 m^3 $year^{-1}$
Total:	280×10^6 m^3 $year^{-1}$

Methods

From January of 1985 to December of 1988, we took samples of water every month at seven sites of the Albufera Lagoon. We analysed conductivity and chlorophyll *a* according to the methods summarised by GOLTERMAN et al. (1978). We obtained daily rain data from the database of the Confederación Hidrográfica del Júcar (Regional Basin Board), whereas the intensity of the rain in November 1988 was obtained from the Automatic System of Hydrologic Information (SAIH Júcar). The source of the daily level data of the Albufera comes from the Drainage Committee of Albufera.

Results and discussion

During our survey period of the Albufera, flash floods occurred in 1986, 1987 and 1988. The running waters and the reduction of the

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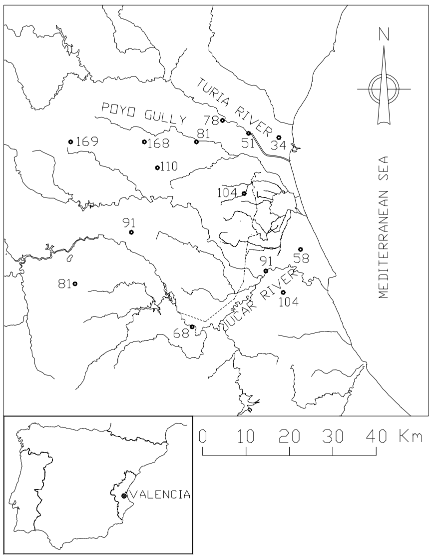

Fig. 1. Location of study area. Discontinuous line indicates the Royal Channel of the Júcar River. Continuous lines indicate the main channels and rivers. The points indicate rainfall measuring sites and the sum of rain during the survey.

renewal time of the lagoon cause the sudden changes in the physico–chemical and biological properties of the water. This is demonstrated by the temporal change of the conductivity and chlorophyll *a* against the monthly rainfall in Sueca (Fig. 2). During dry periods, conductivity and chlorophyll *a* values increase over time, whereas during the rain events, the renewal of the Albufera by running waters results in declines in these measurements amounting to half the previous values. This was clearly the case in autumn 1986 (Fig. 2). The determination coefficient between the monthly rainfall and conductivity within this sampling period (1985–1988) was 0.33 (Fig. 3), and the correlation was r = –0.57 (n = 30, P < 0.001). However, the determination coefficient between the monthly rainfall and chlorophyll *a* is lower, only 0.13, and the correlation r = –0.36 (n = 28, P < 0.05); we would expect the biological response to be lower.

In 1986, the average decrease of conductivity after the rainfall in the Albufera Lagoon was about 59% over the preceding September data. This amount was similar to that obtained on the same days by ORTEGA et al. (1988) in Moro Gully (Segura River watershed, 200 km to the south), where the decrease of conductivity was 65%.

From weather data from 10 to 12 November 1988, there was a cold cyclone from the Atlantic Ocean to the Mediterranean Sea in the high level of the atmosphere. Humid winds from the sea occurred at a lower level. This combination produced heavy storms and local problems. Rainfall data during this period at several sites of the Albufera basin are summarised in Fig. 1.

The rain was more intense during the morning and evening of November 11 (Fig. 4). The

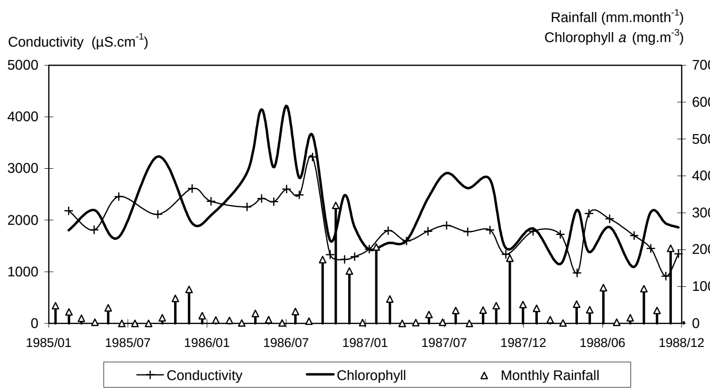

Fig. 2. Evolution of the values of conductivity and concentration of chlorophyll *a* in each sample and the monthly rainfall in Sueca during the 4-year sampling period.

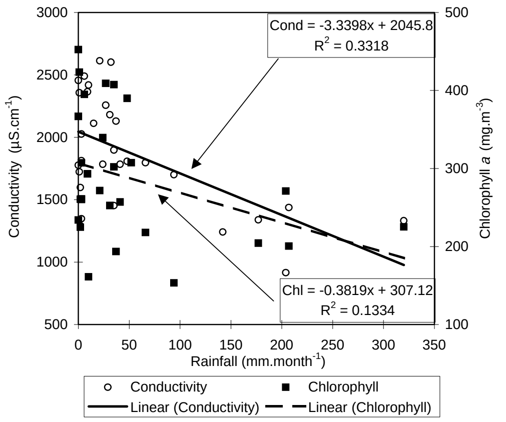

Fig. 3. Representation of the conductivity and chlorophyll *a* against the monthly rainfall. Lines indicate the regression.

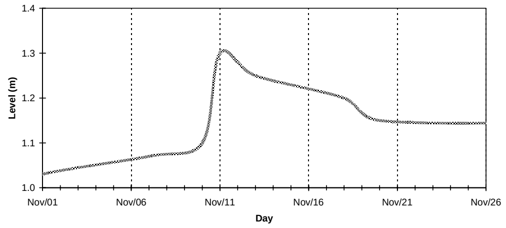

Fig. 5. Level of the Albufera Lagoon during November 1988.

level of the water in the Albufera increased from 1.07 m (November 8) to 1.30 m (November 11) and decreased to 1.25 m (November 14) (Fig. 5). The change in the volume of the lagoon was 4.88×10^6 m^3. The increment in 2 days was 18% as compared to the volume of 27.1×10^6 m^3 in the previous days. The increase of volume was attributed to the rain over the lagoon (1.23×10^6 m^3), the running waters from the Poyo Gully (1.28×10^6 m^3, CAMARASA 1995) and 2.37×10^6 m^3 from the other gullies, ditches and channels. This increase was similar to that recorded in Moreton Bay, SE Queensland, Australia (HEIL et al. 1999), in May 1996.

The physico–chemical properties of the waters changed suddenly. Table 1 shows the data for four sampling sites in the Albufera some days before and after the rains. The waters flowing into the northern side of the lagoon flowed out to sea on the eastern side. The conductivity values were similar in October to those in November. The decrease in conductivity in the western and southern sides was larger than that in the northern side, about 60% over preceding data. The consequence was that the northern and eastern sides were diluted in the same proportion to the increase of the lagoon volume (18%), whereas in the western and southern sides this proportion was greater (60%). This is because the rain over the rice field drains via the ditches into the channels that flow into the western and southern side of the lagoon, flowing to the sea by the natural outlet in the south-east. We suggest that the inflow would have been about 10×10^6 m^3 to obtain the dilution value measured.

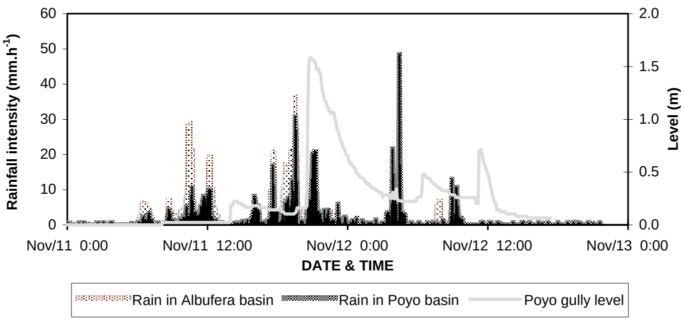

Fig. 4. Distribution of the 5-min values of rain intensity measured in the basin of the Poyo Gully and the Albufera Basin and evolution of the water level in the Poyo Gully from 10 to 12 November.

Table 1. Values of conductivity and chlorophyll *a* in four sites of the Albufera and the difference in % between the sampling before and after the storm.

	Oct. 15, 1988	Nov. 19, 1988	Difference
Conductivity (µS cm^{-1})			
SITE 1, North side	1610	1320	–18%
SITE 2, East side	1640	1360	–17%
SITE 3, West side	1280	510	–60%
SITE 4, South side	1280	470	–63%
Chlorophyll *a* (mg m^{-3})			
SITE 2, East side	455.8	339.2	–26%
SITE 3, West side	425.7	327.8	–23%
SITE 4, South side	269.0	102.2	–62%

In the eastern and southern sides, the proportion of decrease in the concentration of chlorophyll *a* was the same as the conductivity. However, in the western side, the conductivity proportion decreased by 60%, whereas the chlorophyll *a* decreased only by 23%. We hypothesise that in this side of the lagoon the flow of water is slower than in the south-east, and the phytoplankton bloom (caused by the increase in nutrients; HEIL et al. 1999) maintains algal density more easily than near the outflowing channel, where the algae are transported to the sea.

Conclusions

These events, involving heavy storms and floods, show the influence of rainfall over the limnological characteristics of the Albufera Lagoon. The running waters coming from heavy rains cause drops in conductivity and chlorophyll *a* values that correlate well with the measured rainfall. In areas where the flow is slow, the conductivity decreases more that the concentration of photosynthetic pigments. If the renewal time is very short, both conductivity values and chlorophyll *a* decrease significantly. During the periods of drought, the conductivity of the waters increases.

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