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PII: S0043-1354(99)00102-5

Wat. Res. Vol. 34, No. 1, pp. 334–342, 2000

Printed in Great Britain
0043-1354/99/$ - see front matter

ENVIRONMENTAL IMPACTS OF INTENSIVE AQUACULTURE IN MARINE WATERS

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(First received 1 January 1998; accepted in revised form 1 February 1999)

Abstract—The effects of marine aquaculture on the environment were evaluated by studying the water quality of San Pedro river, a canal located within the Bay of Cádiz (SW of Spain). Marine aquaculture, both extensive and intensive, is one of the most important activities carried out in this area. Several facilities are located on this river, the most important being devoted to the intensive culture of Gilthead Seabream (*Sparus aurata*). The characterization of the water consisted of the evaluation of the variation of several parameters along the river and during different seasons. These parameters were pH, temperature, salinity, dissolved oxygen, suspended solids and nutrients (ammonium, nitrite, nitrate and phosphate). With a water quality criteria based on local laws, a significant but not dangerous pollution was observed in the area, with ammonium and suspended solids being the most significant pollutants.

Key words—pollution, seawater, marine aquaculture, environmental impact

INTRODUCTION

In recent years, aquaculture production has increased worldwide, mainly due to the increasing demand for aquaculture produce, and the need for new food supplies. This development generates profit and income, but it also bears risks of negative environmental impact, such as pollution, landscape modification, or biodiversity change. The main input in most intensive fish culture systems is fish feed, which is partly transformed into fish biomass and partly released into the water as suspended organic solids or dissolved matter such as carbon, nitrogen and phosphorus, originating from surplus food, faeces and excretions via gills and kidneys. Other pollutants are residuals of drugs used to cure or prevent diseases.

It should be recognized that to date the majority of aquaculture practices have had few adverse effects on ecosystems (Barg, 1992). Nevertheless, some cases of environmental degradation in coastal areas have occurred due to, for example, intensive cage culture operations in Europe and shrimp farming practices in Southeast Asia and Latin America (Barg, 1992; Sreenivasan, 1995).

In order to reduce the negative impact of aquaculture, governments of several countries are already adopting policies to reduce the pollution of aquatic environments, stressing the importance of studies on the production of waste products in fish farms, (Gonzalez-Vila *et al*., 1996; Twarowska *et al*., 1996; Easter *et al*., 1996), and of the water quality of the environments where effluents are discharged (Cornel and Whoriskey, 1993; Suvapepun, 1994). In this context, this paper is focused on the study of water quality of the San Pedro river, where several companies, which are devoted to intensive marine aquaculture of Gilthead Seabream (*Sparus aurata*), are located. Thus, along the 12 km of the river, eleven sampling stations were selected in order to measure the following variables: pH, temperature, salinity, dissolved oxygen, total suspended solids (SS), total ammonium-nitrogen, nitrites, nitrates and inorganic phosphorus. The selected parameters were used to evaluate the water quality of the San Pedro river and to assess the environmental impact of marine aquaculture.

STUDY AREA

The study area included the San Pedro river and its surroundings (SW Spain), where several marine aquaculture facilities are located, the total area being about 32 km^2 (see Plate 1). The San Pedro river was a tributary of the Guadalete river, but it was artificially blocked 12 km from the mouth. So, actually the San Pedro river is an arm of the sea with a length of 12 km, a width ranging between 15

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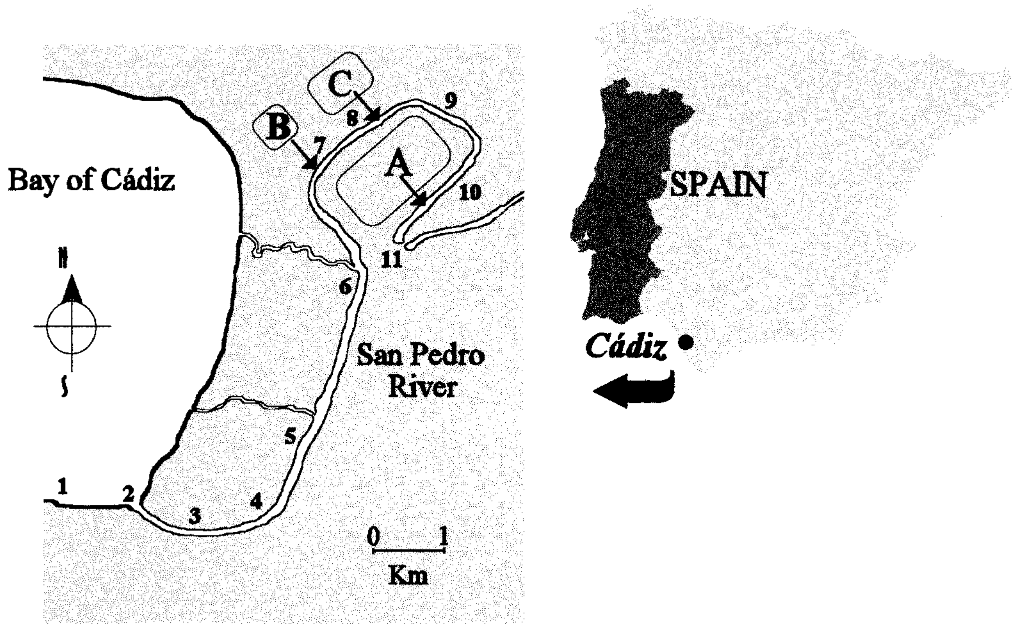

Plate 1. Geographical situation of the San Pedro river and corresponding sampling stations. Thin arrows indicate fish farms effluents.

and 30 m and a maximum depth of 3–4 m. Its water renovation, from the Bay of Cádiz, is controlled by tidal cycles. The freshwater input is seasonal and relatively low, and so the water of the river is seawater in character. The San Pedro river is affected by a semi-diurnal tidal range, with the height of the water column varying from 3.5 m at spring tide to 0.5 m at neap tide.

Three fish farms are located along the river. One of them (A in Plate 1) is relatively large enough to be considered as the main source of potential pollution in the river. This farm, with an extension of about 1,300,000 m^2, consists of a series of batteries of sand ponds where about 1000 Tn/year of Gilthead Seabream are cultured in an intensive regime. Daily, a volume of water of 240,000 m^3 is taken from the San Pedro river and a similar volume of effluent is poured into the river.

The San Pedro river is located within a protected area (The Natural Park of the Bay of Cádiz), which promotes especially strict requirements in the water quality of the river (BOJA, 1997).

MATERIALS AND METHODS

Reagents and solutions

All the reagents used in this work were of analytical grade and purchased from Merck (Daarmstadt, Germany). To evaluate the concentration of potential pollutants in seawater, corresponding calibration plots were constructed of six points each. Except for the phosphate calibration solutions, all the solutions were done with synthetic seawater, which was prepared by dissolving the needed amounts of salts to a final composition, in g l^{-1}, of: 23.926 (NaCl); 4.008 (Na_2SO_4); 0.677 (KCl); 0.196 ($NaHCO_3$); 0.098 (KBr); 0.026 (H_3BO_3); 0.003 (NaF); 10.826 ($MgCl_2.6H_2O$); 1.518 ($CaCl_2.2H_2O$); 0.024 ($SrCl_2.6H_2O$).

Water sampling

During the second half of 1996, three sampling expeditions were carried out in the San Pedro river at two month intervals. The first and third expeditions took place at low tide, while the second was at high tide. The third expedition was carried out after a period of rain. Eleven points were selected along the river for collecting the samples. During each sampling expedition, two water samples were collected at each point, at two different tide situations (rising tide and ebb tide). The tide situation for each sampling expedition is shown in Table 1. From the procedure described it follows that water composition was estimated up to six times for each selected point.

Two different bottles were used for taking each sample: A 1-l polyethylene bottle was used for the sample for quantifying suspended solids and ammonium. A 1-l glass bottle was chosen for the sample used to determine nitrites, nitrates and phosphates. As a biocidal agent, 40 mg/l $HgCl_2$ were added to preserve the latter sample.

Determination of properties of the water

Measurements of temperature, salinity, dissolved oxygen and pH of seawater were performed *in situ* during the sampling process, at a depth of 30 cm. Suspended solids, ammonium, nitrite, nitrate and phosphate were quantified in the laboratory. Water samples were firstly filtered by using a 0.45 μm filter (HAFT04700, Millipore, USA) and then analyzed by applying standard methods (Grasshoff *et al.*, 1983, Rodier, 1990), which are given in Table 2.

RESULTS AND DISCUSSION

The quality of seawater and subsequent effect of marine aquaculture in the environment was evaluated by analyzing the parameters mentioned above in the eleven sampling stations selected along the

Table 1. Description of tide situation on sampling expeditions

Sampling expedition	Curve	Tide situation
First (August 1996)	1	Low and ebb tide (1 h 30 min before low tide)
	2	Low and rising tide (5 h 30 min before high tide)
Second (October 1996)	3	High and rising tide (2 h before high tide)
	4	High and ebb tide (5 h 30 min before low tide)
Third (December 1996)	5	Low and ebb tide (2 h 30 min before low tide)
	6	Low and rising tide (6 h before high tide)

river. The results obtained were graphically represented and are shown and discussed as follows:

pH

The results obtained are shown in Fig. 1. As can be seen, the river can be divided into two different zones. In the first, from the mouth of the river to sampling station number 6, the pH showed small variations and was probably largely determined by the acidity of the seawater of the bay. The second zone, from sampling station number 6 to number 11 (at the end of the river), was affected by the activities of several companies dealing in marine aquaculture. These activities caused a marked decrease in the pH of the water, the lowest values being at sampling station number 11, where the most important effluent inputs are located. The higher acidity of this effluent was confirmed with a sample of this effluent, which was taken during each sampling expedition. When the pH of these samples was measured, values ranging between 7.2 and 7.4 were obtained. This is probably due to the high concentration of ammonium in the effluent and to the acidic character of the faeces and fish food.

On the other hand, for the same sampling expedition, the pH was observed to be independent of the tide situation. Thus, similar results were obtained on rising and ebb tide. This effect was observed in all the parameters studied in the present work.

Temperature

In all the samplings, the temperature did not vary along the river, and normal seasonal variation was observed (see Fig. 2).

Salinity

The variation of salinity is shown in Fig. 3. The expected behavior was observed in the first four curves (1–4), which show seasonal effects and, again, the river can be divided into two different zones; with the upstream zone having higher salinity due to the poor renovation of the water in this part of the river. As mentioned before, the samples represented in curves 5 and 6 were taken after a strong period of rains, which produced a marked decrease in salinity. The shape of these two curves confirmed the poor water renovation in the second zone of the river, where highest level of pollution can be found.

Dissolved oxygen

The variation of this parameter is represented in Fig. 4. The dependence of dissolved oxygen on temperature and salinity can be observed, especially in curves 1 and 2. On the other hand, once again, the behavior of the two zones of the river is clearly different, with the aquaculture activities being responsible for the low values recorded in the second half of the river, probably due to the high consumption of dissolved oxygen into the fish farm and to the redox processes involved in the degradation of nutrients. Thus values down to 2 mg/l were obtained when the main effluent was directly measured.

Suspended solids

As is well-known, the high amounts of solids present in waste effluents is potentially one of the most important environmental problems of aquaculture. Fig. 5 shows the variation of suspended matter in

Table 2. Variables studied and corresponding methodology

Variable	Method
pH	Potentiometry
Dissolved Oxygen	Voltamperometry
Salinity	Conductivity
Temperature	Digital thermometer
Suspended solids	Filtration and weigh
Ammonium	Spectrophotometry (Indophenol blue)
Nitrite	Spectrophotometry (Sulfanilamide/N-(1-Naphthyl)-ethylenediamine dihydrochloride)
Nitrate	Spectrophotometry (reduction in Cd column and nitrite method)
Phosphate	Spectrophotometry (Ammonium molybdate/ascorbic acid)

the water of the San Pedro river. A seasonal dependence is clearly observed. During summer, activity, feeding and growth of fishes is greatest, corresponding to maximum concentrations of solid suspended matter (curves 1 and 2). These concentrations increased notably in the second part of the river, as a direct consequence of the marine culture activities.

Nutrients

The concentration of ammonium, nitrite, nitrate and phosphate are given in Figs 6–9, respectively. The pattern of all four nutrients along the river shows some similarities, with maximum concentrations found in the upper part of the river, where fish farms are located. However, while in curves 1, 2, 5 and 6, (first and third samplings) the inflection points of the curves were at station number 6, in curves 3 and 4 (second sampling), a displacement was observed and the increment in the concentrations of nutrients started at station number 8. This effect can be explained by the tide situation. While the first and third sampling expeditions were carried out at low tide, the second was at high tide, and an evident displacement of the water located at the end of the river (containing the nutrients) was produced.

It is important to mention the high levels of ammonia measured at the end of the river, where fish farm effluents flow into the river. Thus, concentrations greater than 2.5 mg l^{-1} were quantified in the second sampling expedition (curves 3 and 4). In curves 5 and 6 (third sampling expedition), the observed dilution effect was attributed, as mentioned before, to the rainfall prior to sampling. However, as can be observed in Figs 7 and 8, these rains caused an increment in the concentration of nitrites and nitrates, due to the run-off coming from agricultural land located around the river.

CONCLUSIONS

From the point of view of water quality the San Pedro river can be divided into two different zones. The first, with a length of about 8 km, goes from the mouth to sampling station number 6. In this zone, where there are no fish farms, the characteristics of the water were very similar to those found in the water of the bay. This indicates that, in this first zone, there is a good renovation of the water controlled by the tides.

The second part of the river is from sampling station number 6 to the end of the river (sampling station number 11), and it is about 4 km long. In this zone, three fish farms are located, and their effluents are probably responsible for the poorer water quality observed. In this sense, all the parameters which were studied showed significant variations in this upper part of the river. In general, all these variations were a consequence of aquaculture

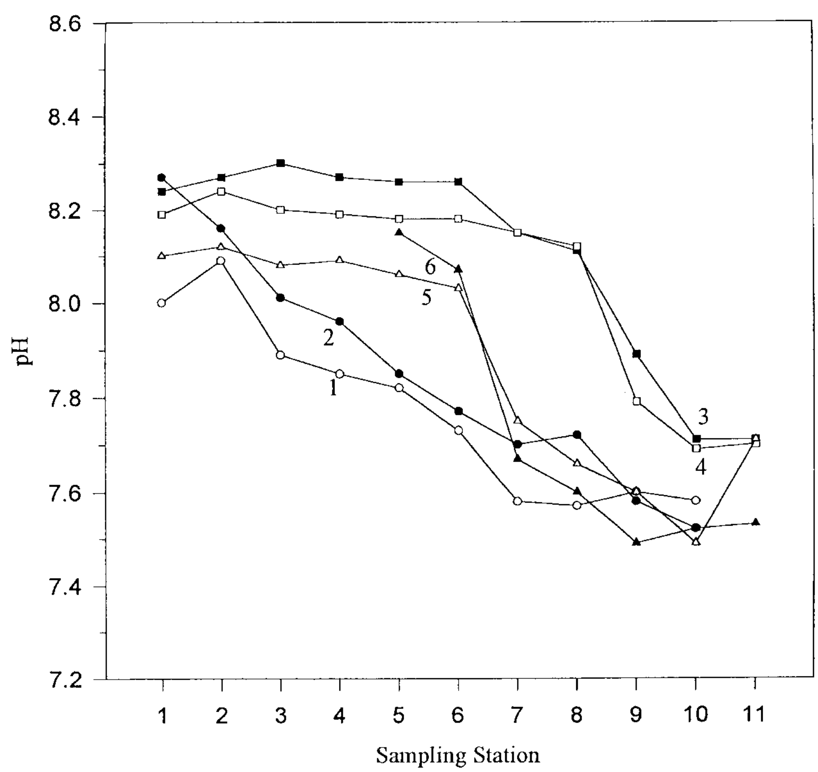

Fig. 1. Variation of pH in water of San Pedro river. Description of curves is given in Table 1.

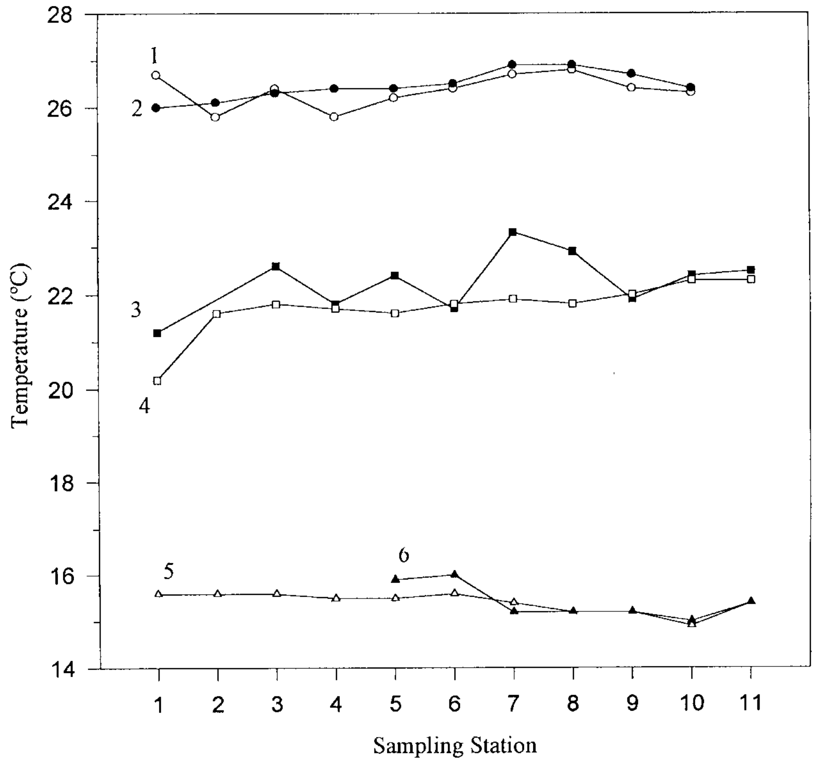

Fig. 2. Variation of temperature in water of San Pedro river. Description of curves is given in Table 1.

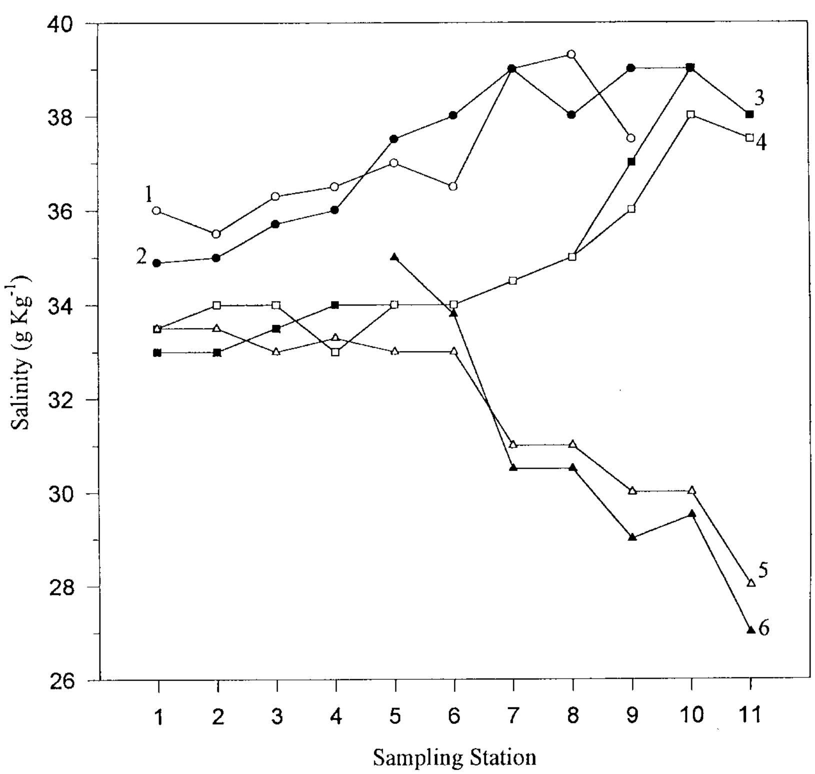

Fig. 3. Variation of salinity in water of San Pedro river. Description of curves is given in Table 1.

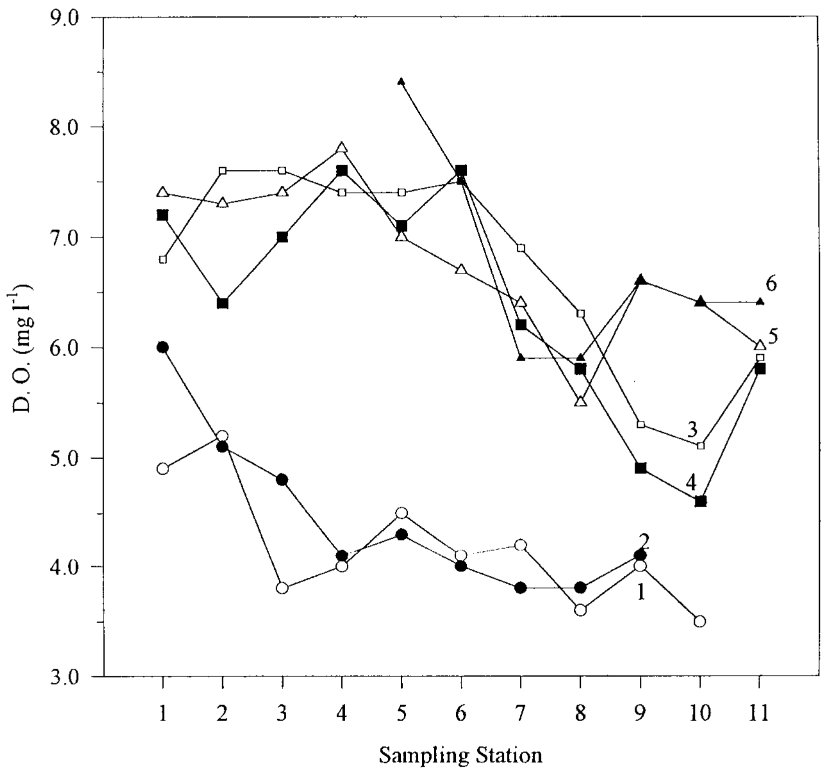

Fig. 4. Variation of the concentration of dissolved oxygen in water of San Pedro river. Description of curves is given in Table 1.

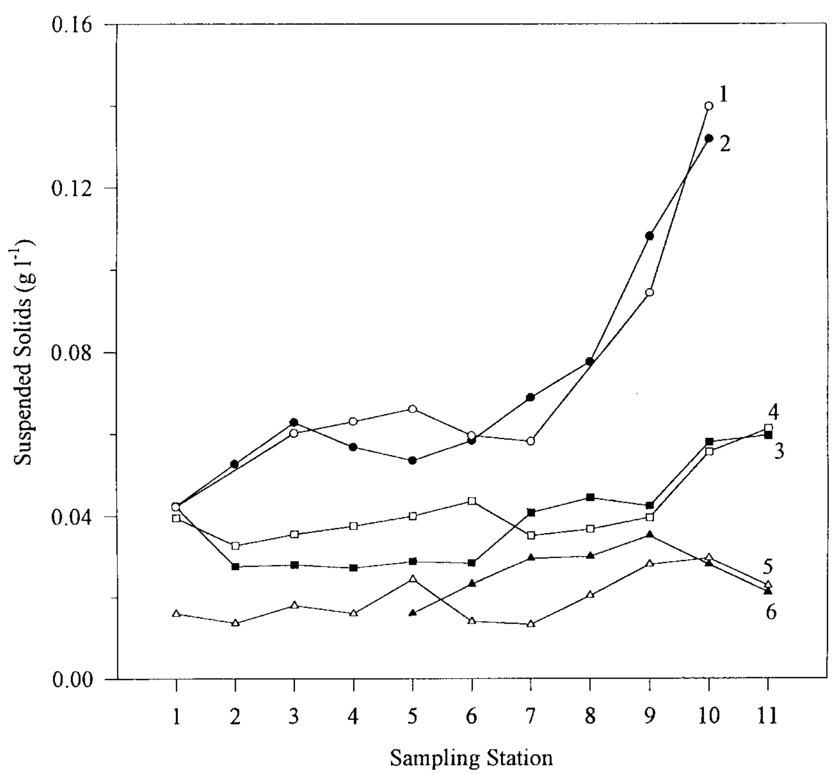

Fig. 5. Variation of suspended solids in water of San Pedro river. Description of curves is given in Table 1.

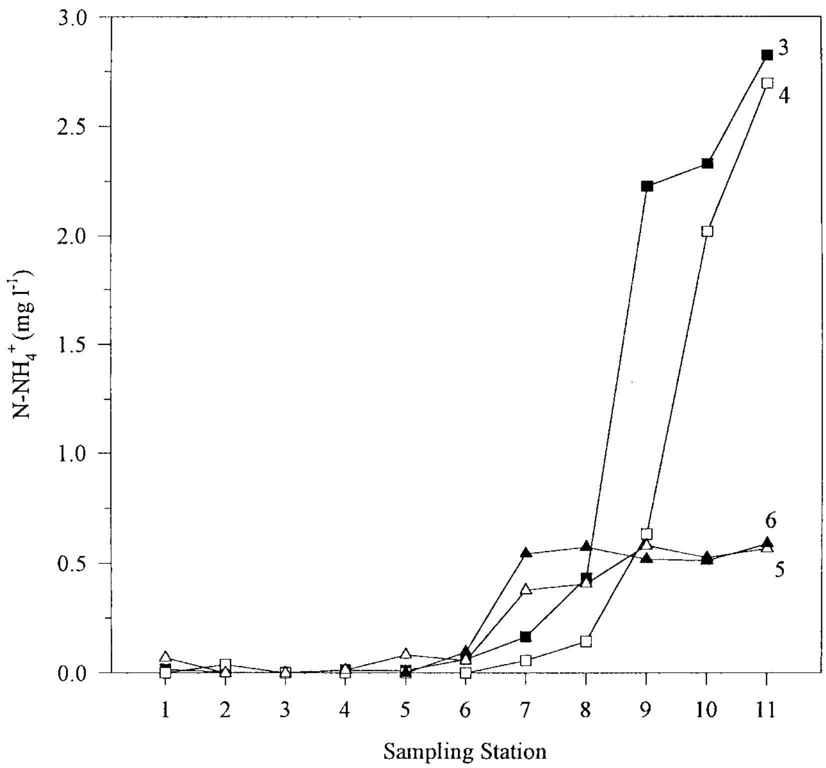

Fig. 6. Variation of ammonium (as nitrogen concentration) in water of San Pedro river. Description of curves is given in Table 1.

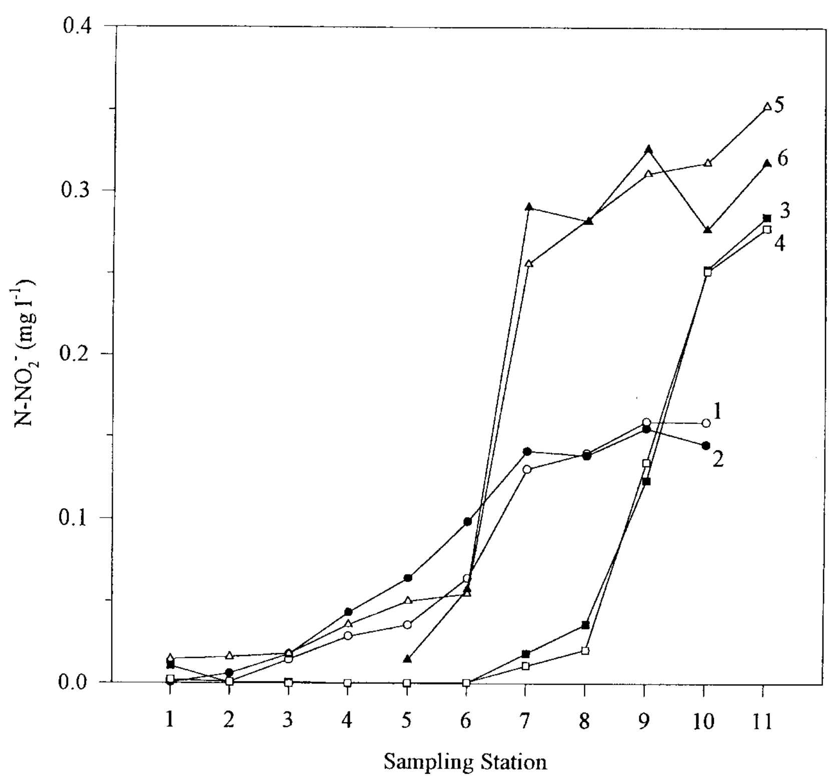

Fig. 7. Variation of nitrites (as nitrogen concentration) in water of San Pedro river. Description of curves is given in Table 1.

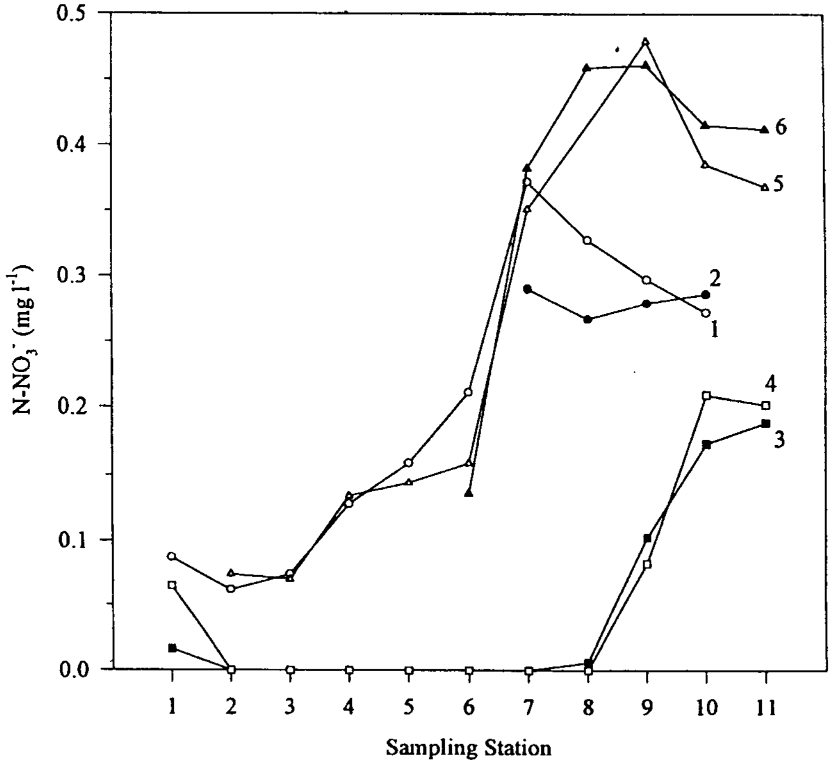

Fig. 8. Variation of nitrates (as nitrogen concentration) in water of San Pedro river. Description of

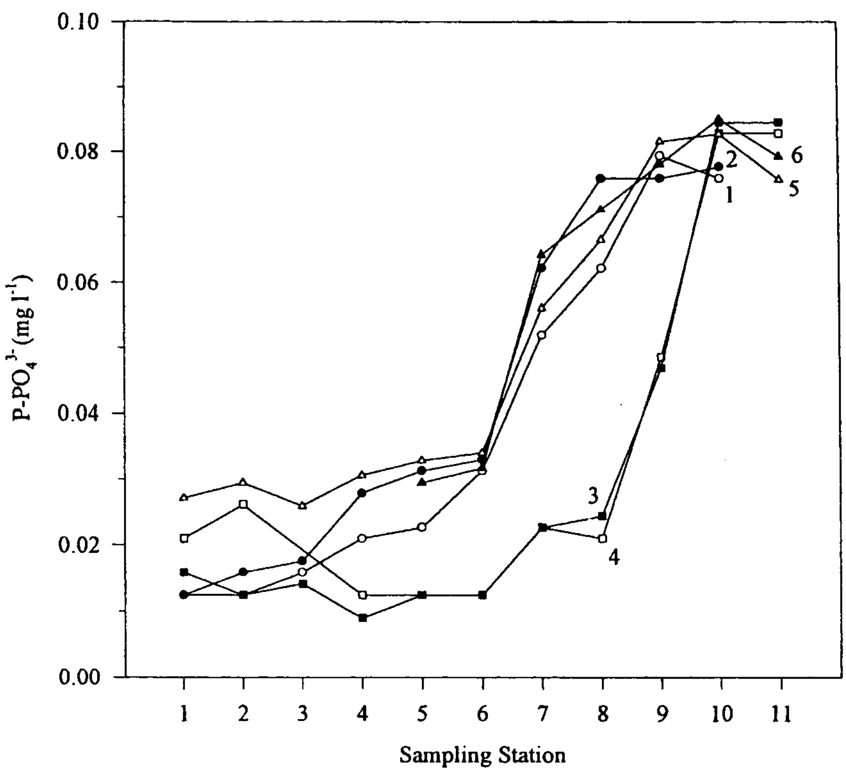

Fig. 9. Variation of phosphates (as phosphorus concentration) in water of San Pedro river. Description of curves is given in Table 1.

Table 3. Obtained and reference values for studied variables

Variable	Reference value I[a]	Reference value II[b]	Worst M. V.[c]	Mean M. V.[d]
pH	7–9	6–9	7.49	7.7
Dissolved oxygen	80% saturation	60% saturation	53.2% saturation	74.0% saturation
Salinity[e]	0.9–1.1 M	0.9–1.1 M	1.2 M	1.1 M
Suspended solids[e]	1.15 M	1.3 M	2.7 M	1.6 M
N-NH_4^+	600 mg NH_4^+/l	1200 mg NH_4^+/l	3633 mg NH_4^+/l	997 mg NH_4^+/l
N-NO_2^-	600 mg NO_2^-/l	1000 mg NO_2^-/l	1160 mg NO_2^-/l	558 mg NO_2^-/l
N-NO_3^-	700 mg NO_3^-/l	1400 mg NO_3^-/l	2121 mg NO_3^-/l	1108 mg NO_3^-/l

[a]Reference value for protected areas, based on local laws (BOJA, 1997) (of application in the San Pedro river).
[b]Reference value for non-protected areas, based on local laws (BOJA, 1997).
[c]Worst measured value.
[d]Mean measured value in the upper zone of the river (sampling stations 6–11).
[e]As variation of the mean value in non-polluted zone, M.

activities together with poorer renovation of water by the tides. As the most representative variations, we could mention those observed for dissolved oxygen, suspended solids and nutrients, specially for ammonium, which, as is well-known, is indicative of recent pollution.

Table 3 shows, as a résumé, the obtained results in two columns, containing the worst measured values and an average of the values obtained in the upper zone of the river, where fish farms are located. This table also includes two reference values for each variable. The first one contains the maximum values allowed for the variables studied in the water of the San Pedro river, based on local laws (BOJA, 1997), taking into account the particular situation of protected area. The second reference column shows the water quality criteria, based on local laws (BOJA, 1997), which would be of application in the more general case of non-protected areas. As can be seen, almost all the variables (especially dissolved oxygen, suspended solids and ammonium) present at least one very high value, usually measured in stations 10 or 11. The mean values obtained in the upper zone of the river show some deviations by comparing with the reference values for protected areas, and then, the existence of a significant pollution can be concluded. Nevertheless, if the mean values are compared with the reference values for non-protected areas (to extrapolate to other fish farms) we could conclude that all the values except for suspended solids would be included within the allowed range. In the case of nitrate, as mentioned before, some very high measured values were considered as outliers and caused by the effect of rains. Thus, such high values can not be attributed to aquaculture activities.

Finally, although responsible for water renovation, the tide situation did not control the variations of the studied parameters. Thus, similar values were measured for both rising and ebb tide.

Acknowledgements—This work was supported by the CICYT (Spanish Commission for Research and Development), project No. PTR 95-0087-OP.

REFERENCES

Barg U. C. (1992) Guideline for the promotion of management of coastal aquaculture development. FAO Fisheries Technical Paper. No. 328., 122p. Rome, FAO.

BOJA (1997) Boletín Oficial de la Junta de Andalucía (Official Bulletin of Andalusian Autonomous Government), núm. 27, 2591–2598.

Cornel G. E. and Whoriskey F. G. (1993) The effects of rainbow trout (*Oncorhynchus mykiss*) cage culture on the water quality, zooplankton, benthos and sediments of Lac du Passage, Quebec. *Aquaculture* **109**(2), 101–117.

Easter C. C., Novak J. T., Libey G. S. and Boardman G. D. (1996) Waste characterization and disposal from a recirculating aquaculture system producing hybrid striped bass. In: Aquaculture Engineering Society Proceedings II: Successes and Failures in Commercial Recirculating Aquaculture, 2. Northeast Regional Agricultural Engineering Service, pp. 441–446.

Gonzalez-Vila F. J., Del Rio J. C., Mancha A., Bautista J. M. and Martin F. (1996) Origin and environmental significance of organic deposits in aquatic sediments. *Fresenius Environ. Bull.* **5**(3–4), 161–166.

Grasshoff K., Ehrhardt M. and Kremling K. (1983) *Methods of Seawater Analysis*, 2nd. Verlag Chemie, Germany.

Rodier J. (1990) *Análisis de las Aguas*. Omega, Spain, (in Spanish).

Sreenivasan A. (1995) Pollution from industrial shrimp culture: A serious environmental threat. *Fish. Chimes* **15**(5), 19–20.

Suvapepun S. (1994) Environmental impacts of mariculture. NRCT-JSPS Joint Seminar on Marine Science. Chulalongkorn University, Thailand. pp. 25–29.

Twarowska J. G., Westerman P. W. and Losordo T. M. (1996) Water treatment and waste characterization evaluation of an intensive recirculating fish production system. In: Aquaculture Engineering Society Proceedings II: Successes and Failures in Commercial Recirculating Aquaculture, 2. Northeast Regional Agricultural Engineering Service, pp. 447–460.