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EFFLUENT CHARACTERISTICS AND NUTRIENT LOADING OF A SEMI-INTENSIVE SHRIMP FARM IN NW MEXICO

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SHRIMP FARM
EFFLUENTS
SUSPENDED MATTER
NUTRIENT LOADS
EUTROPHICATION

ABSTRACT. – An evaluation of the characteristics of the influent and effluent water of a semi-intensive shrimp farm of Sonora that operated with one cycle of six months, a mean water exchange of 12.7%$\cdot$d^{-1} and had mean final yields of 2,000 ± 85 kg$\cdot$ha^{-1} (FCR = 2.15 ± 0.21), showed that during that cycle the farm discharged 547 kg N$\cdot$ha^{-1} and 73 kg P$\cdot$ha^{-1}. The respective net exports were 122 kg N$\cdot$ha^{-1} and 14 kg P$\cdot$ha^{-1}. The total solids discharged were 20.8 tons$\cdot$ha^{-1} (73.4% inorganic) and the net amounts exported were 7.52 tons$\cdot$ha^{-1} of inorganic particulates and 0.92 tons $\cdot$ha^{-1} of organic suspended matter. The water body that receives these discharges is the Moroncarit lagoon, which has an estimated mean water residence time of 3 to 5 d and receives also agricultural drains and sediments of marine origin. For this reason, the nutrients and the sediments discharged by this farm could contribute significantly to the evolution of this lagoon, as well as to its trophic status.

INTRODUCTION

One of the main constraints for the development of aquaculture is its real or perceived impact on the health of the environment caused by its effluents, that are a potential source of eutrophication of coastal areas (Barg 1992, Bardach 1997). This is affecting the growth of an important section of this industry, represented by shrimp farming, that grew rapidly in the last two decades. In recent years its worldwide annual productions, close to 0.8-0.9$\cdot$10^6 metric tons, represent nearly 30% of the shrimp supplied to the world markets and are an important component of the economy of inter-tropical countries of Asia and Latin America (Rosemberry 1998).

Thus, the characterization of shrimp farm effluents and the quantification of the amounts of nutrient discharged is important for the health of this industry, as well as of the environment, because it would permit a realistic assessment of the impact on the receiving water bodies and a regulation of the industry based on hard facts, rather than on perceived threats (GESAMP 1996, Fuchs *et al.* 1999).

There are several examples of this type of studies (Hopkins *et al.* 1993, Briggs & Funge-Smith 1994, Páez-Osuna *et al.* 1997) but the results vary widely, because of the different levels of technology, culture intensity, rates of feeding and water exchanges (Boyd & Gautier 2000).

In NW Mexico shrimp culture has grown with an accelerated pace, from the first semi-intensive farm that started operations in 1985 in 150 ha of pond surface, to the 754 farms and more than 60$\cdot$10^3 ha of ponds, that are concentrated in the coastal states of the Gulf of California, mainly in the states of Sinaloa (41,557 ha = 69.3% of the total pond surface) and Sonora (13,941 ha = 23.2%) (SAGARPA 2004).

There is some information on the characteristics of the effluents of the farms of Sinaloa, that operate with two cycles$\cdot$year^1 and use low water exchanges (2-3% to 6-8%$\cdot$d^{-1}) because of the sub-humid climate and mild winters, whereas none is available for those of the state of Sonora, that has an arid climate and cold winters. For these reasons, these farms operate with one cycle$\cdot$year^{-1} and the mean water exchanges are > 10-12%.

The aim of this study was to evaluate the water characteristics of the intake and effluents of a semi-intensive farm of the state of Sonora and, using these data and the records of pond management, calculate the amounts of solids and nutrients discharged by this farm during the 2003 production cycle.

METHODS

The Chomojabiri farm is located in the southern part of the state of Sonora, between coordinates 26º 42.312' to 26º 42.615' Lat N and 109º 37.596' to 109º 37.858' Long W (Fig. 1). It was

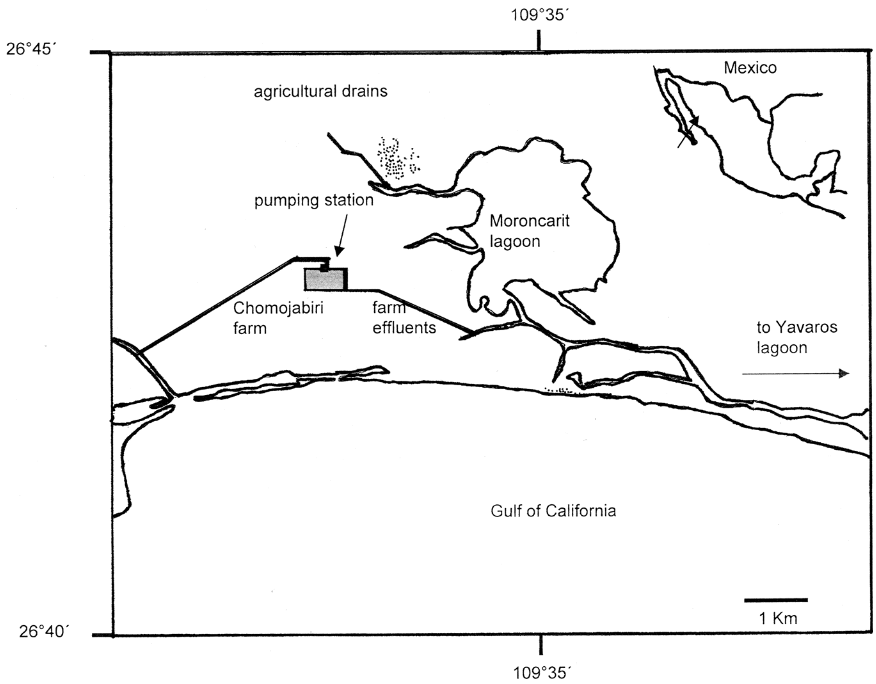

Fig. 1. – Location of the Chomojabiri farm, of its influent and effluent, and of the Moroncarit lagoon.

selected because, in view of its small dimensions (9 ponds for a total of 23 ha), it had only one biologist in charge and the criteria and routines of pond handling were the same for all ponds. Therefore, it was assumed that the data obtained in the influent and effluent waters of ponds 1 and 2 (6.9 ha = 30% of the total pond surface) could be used as representative of the influent and effluent characteristics of the whole farm.

The production cycle started at the end of April 2003 and lasted 185 d and 194 d for ponds 1 and 2. In both, the initial density was 20 $PL \cdot m^{-2}$, fertilizers (85 kg of urea and 12 kg of monoammonium phosphate$\cdot ha^{-1} \cdot cycle^{-1}$) were applied after 7, 22 and 51 d. Food was supplied in three equal parts every 8 h, with daily rations that decreased progressively and ranged from 28% of the estimated shrimp biomass during the first two weeks, to 2.2% at the end of the cycle. The phosphorus and protein content of shrimp feed were 1.05 to 35% and the amount of food supplied throughout the cycle was 4,295 ± 255 $kg \cdot ha^{-1}$.

Water exchanges started after 29 d and ranged between 5% and 20% of the total water volume. The highest was during the two weeks before partial harvest, that removed 64% of the evaluated shrimp biomass and took place after 122 d (mean shrimp wet weight = 11.5 ± 3.6 $g \cdot ind^{-1}$). This allowed a reduction of the rate of water exchanges, that varied between 10% and 12% for the remaining 9-10 weeks. The weighted mean exchange rate throughout the whole cycle was 12.7%$\cdot d^{-1}$.

The final shrimp weight was 20.95 ± 3.39 $g \cdot ind^{-1}$, the total yields of ponds 1 and 2 (partial and final harvests) were 1.9 and 2.1 $tons \cdot ha^{-1}$ (mean for the whole farm: 2,000 ± 85.4 kg) and the food conversion ratio (FCR) calculated from the records of all ponds of the farm for the whole cycle was 2.15 ± 0.21.

Every two weeks, four water samples (one every 6 h) were obtained from the common inlet and from the outlets of the two ponds, to determine water temperature, salinity, pH, dissolved oxygen, chlorophyll *a*, suspended matter and dissolved and particulate N and P concentrations. Water temperature, oxygen concentrations and pH were obtained *in situ* with a YSI dissolved oxygen meter and a Corning field pH meter. Salinity was determined with an Atago refractometer. All other samples were preserved in an ice box at 0 ºC. Those for organic N were treated with $5 \cdot 10^{-6}$ M HgCl and the wastes after analysis were stored until disposal, according to the official regulations for toxic substances.

Chlorophyll *a* was determined after extraction with 90% acetone (Strickland & Parsons 1972). Suspended solids were concentrated on preweighed Whatman GF-C glass fiber filters, washed with 5-6 ml of 3% ammonium formate to eliminate sea salt residues, dried to constant weight in an oven at 60 ºC, and ashed later in a muffle furnace at 475 ºC to obtain the inorganic content. The mass of organic solids was calculated by difference between the two values (Wong & Cheung 1999).

The samples for nutrient determination were previously filtered through Whatman GF-C filters. The organic N and the total P content of the particulate retained on the filters were determined with the Kjeldahl method (Rodier 1981), and determining reactive P-PO_4^{3-} after acid persulfate digestion (Hach 1992: methods 8190 & 8048).

The methods for dissolved nutrient analysis in the particle-free water were 8507 (diazotization) for N-NO_2^-, cadmium reduction (8171) for N-NO_3^-, salicylate (8155) for N-NH_4^+ and ascorbic acid (8048) for P-PO_4^{3-}. Total dissolved P was measured with the same method after acid persulfate digestion and the nonreactive fraction was calculated by difference with the untreated samples (Hach 1992). Dissolved organic N was determined with the Kjeldahl method for water samples (Strickland & Parsons 1972).

The total water inputs and outputs were calculated from the ledgers of the pumping station of the farm and from the data of evaporation and precipitation obtained from the Navojoa meteorological observatory of the National Water Commission.

There were no differences between the characteristics of the two effluents, that were different from those of the influent (repeated measures ANOVA tests, $\alpha = 0.05$). For this reason, the mean values of the effluents of each date were compared to the respective values of the influent with Student's t tests for paired samples or with the equivalent nonparametric Wilcoxon's tests, with $\alpha = 0.05$ (Zar 1996).

RESULTS

With the exception of dissolved oxygen and nonreactive P, the mean values of the characteristics of the influent were significantly lower than those of the effluents (Table I). On average, temperature was 1° C higher in the effluent throughout the whole cycle, whereas oxygen concentrations were higher only between days 29 and 100. The pH values were consistently and significantly higher in the effluent, but in both cases they varied within narrow ranges (7.72 ± 0.11 to 8.40 ± 0.24 in the influent and 7.80 ± 0.04 to 8.42 ± 0.19 in the effluent: Fig. 2 A, B, C).

Until partial harvest, salinity was close or more than 10 $g \cdot l^{-1}$ higher in the effluents and ranged between > 50 and 45 $g \cdot l^{-1}$. This difference decreased in the second half of the cycle and salinity was 1 $g \cdot l^{-1}$ lower in the effluent at the time of harvest (Fig. 2 D).

Chlorophyll *a* varied from 0.66 ± 0.19 to 4.57 ± 0.31 $\mu g \cdot l^{l}$ in the influent and from 2.0 ± 1.50 to 10.5 ± 2.33 $\mu g \cdot l^{1}$ in the effluents. With the exception of day 29 concentrations were higher in the effluents, where they

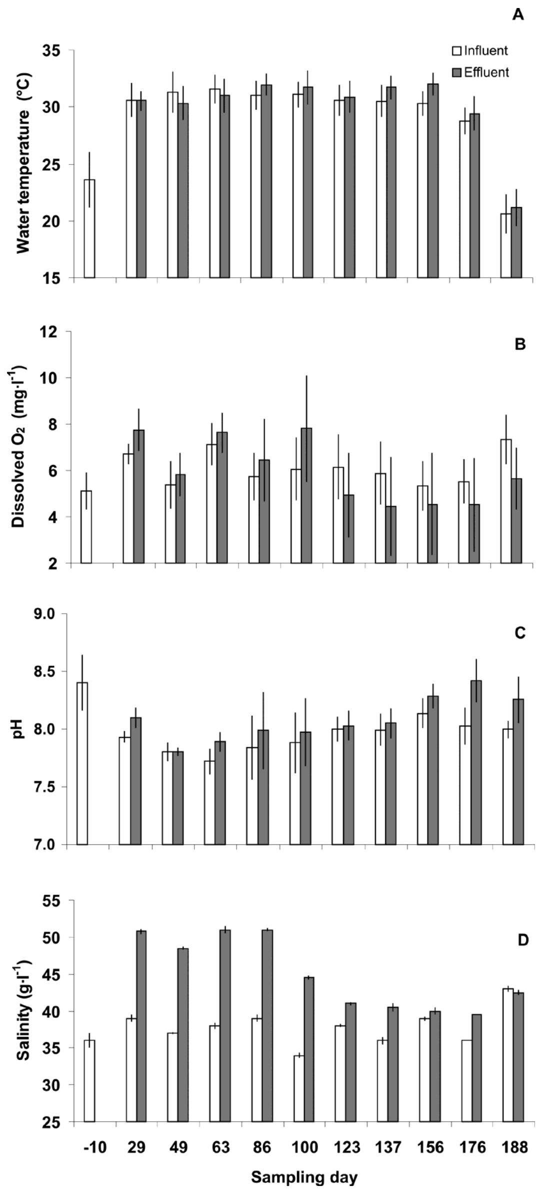

Fig. 2. – Mean values of water temperature (A), dissolved oxygen (B), pH (C) and salinity (D) of the influent and effluents of the Chomojabiri farm. Bars: standard deviation.

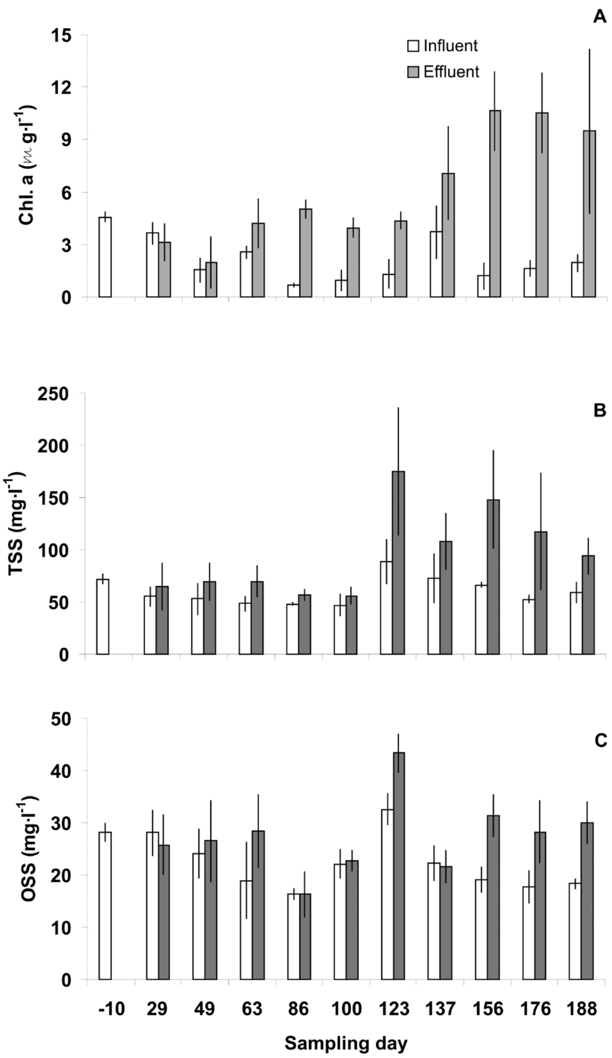

Fig. 3. – Mean concentrations of chlorophyll *a* (A), total suspended solids (B) and organic suspended solids (C) of the influent and effluents of the Chomojabiri farm. Bars: standard deviation.

Table I. – Top, mean values and standard deviations of the water characteristics of the intake and of the effluents of ponds 1 and 2 of the shrimp farm Chomojabiri during the 2003 production cycle. ΣN and ΣP: Total (dissolved + particulate) N and P. ISS, OSS, TSS = inorganic, organic and total suspended solids. Different letters indicate significant differences (Student's t or Wilkinson's tests for paired samples between inlet and mean outlet, α = 0.05). n =10 in all cases. a < b. Bottom, input, discharges and net export of nutrients and suspended solids by the shrimp farm Chomojabiri during the 2003 production cycle. All data are in $kg \cdot ha^{-1}$.

Variable	Inlet	Mean outlet
Temperature (°C)	29.08 ± 3.42 ^{a}	30.07 ± 3.24^b
Salinity ($g \cdot l^{-1}$)	37.59 ± 2.52 ^{a}	44.90 ± 4.84^b
Dissolved oxygen ($mg \cdot l^{-1}$)	6.03 ± 0.74 ^{a}	5.95 ± 1.38^a
pH	7.98 ± 0.18 ^{a}	8.08 ± 0.19^b
$N\text{-}NH_4^+$ ($mg \cdot l^{-1}$)	0.02 ± 0.01 ^{a}	0.06 ± 0.02^b
$N\text{-}NO_2^-$ ($mg \cdot l^{-1}$)	0.02 ± 0.04 ^{a}	0.04 ± 0.01^b
$N\text{-}NO_3^-$ ($mg \cdot l^{-1}$)	0.08 ± 0.02 ^{a}	0.12±0.02^b
Diss. organic N ($mg \cdot l^{-1}$)	0.85 ± 0.19 ^{a}	1.10 ±0.041^b
Part. organic N ($mg \cdot l^{-1}$)	1.02 ± 0.31 ^{a}	1.28 ±0.52^b
∑ N ($mg \cdot l^{-1}$)	2.00 ± 0.51 ^{a}	2.60±0.95^b
$P\text{-}PO_4^{3-}$ ($mg \cdot l^{-1}$)	0.09 ± 0.02 ^{a}	0.12 ±0.02^b
Nonreactive diss. P ($mg \cdot l^{-1}$)	0.03 ± 0.01 ^{a}	0.04±0.02^a
Part. P ($mg \cdot l^{-1}$)	0.16 ± 0.05 ^{a}	0.20±0.05^b
∑ P ($mg \cdot l^{-1}$)	0.28 ± 0.06 ^{a}	0.35±0.08^b
ISS ($mg \cdot l^{-1}$)	37.78 ± 10.51 ^{a}	68.65 ±35.56^b
OSS ($mg \cdot l^{-1}$)	22.54 ± 5.19 ^{a}	27.43 ±7.15^b
TSS ($mg \cdot l^{-1}$)	60.32 ± 13.21 ^{a}	96.07 ±40.90^b
Chl. a (μg·l-1)	2.16 ± 1.29 ^{a}	6.03 ± 3.17^b

Variable	Input ($kg \cdot ha^{-1}$)	%	Discharge ($kg \cdot ha^{-1}$)	%	Net ($kg \cdot ha^{-1}$)	%
Dissolved inorganic N	26	6.1	45	8.3	19	15.6
Dissolved organic N	176	51.4	236	43.1	60	49.2
Particulate organic N	223	52.5	266	48.6	43	35.2
∑ N	425	100.0	547	100.0	122	100.0
Dissolved P	26	44.1	31	42.5	5	35.7
Particulate P	33	55.9	42	57.5	9	64.3
∑ P	59	100.0	73	100.0	14	100.0
ISS	7,730	62.6	15,292	73.4	7,562	89.2
OSS	4,622	37.4	5,539	26.6	917	10.8
TSS	12,352	100.0	20,831	100.0	8,479	100.0
Chl. a	0.35		1.33		0.98	

increased progressively until the end of the cycle (Fig. 3 A).

During the first four months, the concentrations of total suspended solids (TSS) varied between 50 and 75 $mg \cdot l^{-1}$ and were consistently lower in the influent. The high (> 50%) water discharges and other harvest-related activities of day 123 caused a sudden increase, with concentrations of 175-180 $mg \cdot l^{-1}$ in the effluent. After that date, the concentrations of TSS remained high until the end of the cycle (Fig. 3 B). Organic suspended solids (OSS) varied from 16.5 ± 1.2 to 32.6 ± 3.1 $mg \cdot l^{-1}$ in the inflowing water and between 16.3 ± 4.4 and 43.3 ± 3.8 $mg \cdot l^{-1}$ in the discharges (Fig. 3 C). In the influent, the organic content ranged from 31 to 38%, and the mean value was 37.4 ± 3.9%. It varied more widely in the effluent, where the highest organic content of TSS was 40.6%, the lowest was 22.5% and the average was 28.6 ± 8.3%.

There were no clear trends in the concentrations of total dissolved inorganic N ($N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$) of the influent. In the effluent, it increased until day 123, when it decreased because of the 50% water exchange during partial harvest. After that date, the tendency to increase continued for the rest of the cycle (Fig. 4 A).

Dissolved organic N was by far the most important dissolved N fraction in the influent and in the effluent. It varied with a trend similar to that of particulate N, and the respective concentrations ranged from 0.41 ± 0.10 to 1.13 ± 0.24 $mg \cdot l^{-1}$ in the influent and from 0.57 ± 0.25 to 1.84 ± 0.58 $mg \cdot l^{-1}$ in the effluents (dissolved) and from 0.80 ± 0.13 to 1.41 ± 0.21 $mg \cdot l^{-1}$ and between 0.75 ± 0.48 and 2.16 ± 0.48 $mg \cdot l^{-1}$ (particulate). Apart from days 29 and

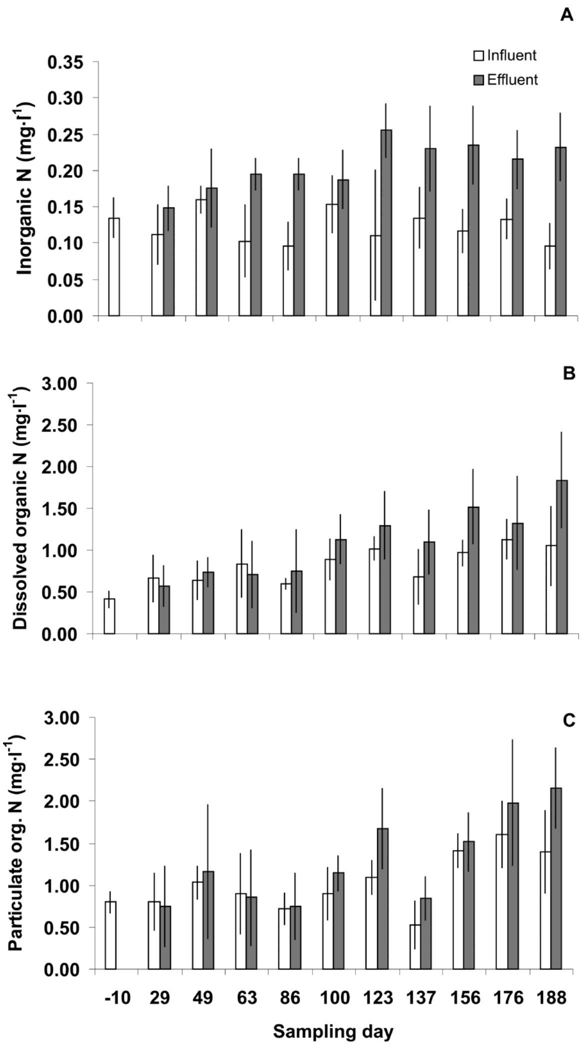

Fig. 4. – Mean concentrations of dissolved inorganic N (A), dissolved organic N (B) and particulate organic N (C) of the influent and effluents of the Chomojabiri farm. Bars: standard deviation.

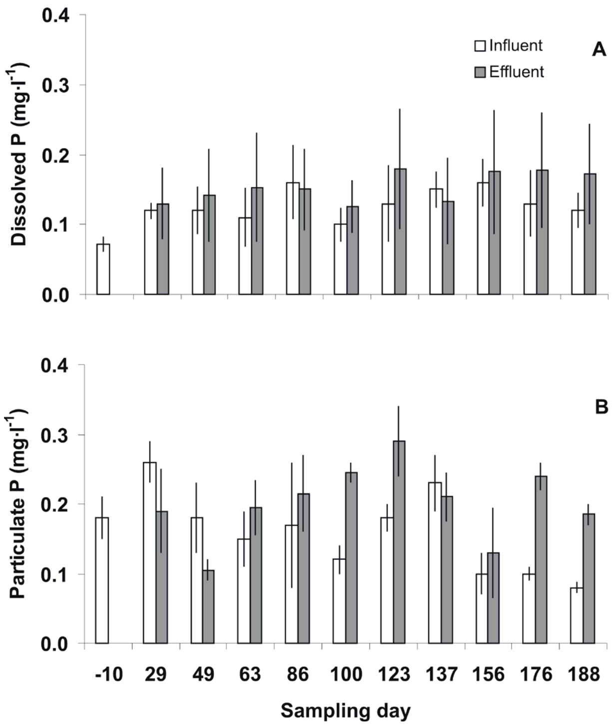

Fig. 5. – Mean concentrations of dissolved (A) and particulate P (B) of the influent and effluents of the Chomojabiri farm. Bars: standard deviation.

63, the values were consistently higher in the outflowing waters (Fig. 4 B, C).

The concentrations of dissolved P tended to be higher in the effluent and during the second half of the cycle (Fig. 5 A). After day 49, those of particulate P were higher in the effluent and showed a clear tendency to increase until partial harvest. After this, they varied without any trend until the end of the cycle (Fig. 5 B).

The nitrogen input due to water exchanges was 425 kg·ha^{-1} (52.5% as organic particulates; the dissolved N species were 41.4% organic and 6.1% inorganic). The total discharges were 547 kg·ha^{-1} and the dissolved organic and inorganic species increased to 43.1% and 8.3%, whereas the organic contribution of particulate N decreased to 48.6%. The net amount of N exported during the cycle was 122 kg·ha^{-1} and the most important was the dissolved organic fraction (49.2%, compared to 35.2% particulate and 15.6% dissolved inorganic N).

The total P content of the influent water was 59 kg·ha^{-1} (44.1% dissolved and 55.9% particulate), and the amount discharged was 73 kg·ha^{-1}, 57.5% of which was particulate. The total P export was 14 kg·ha^{-1} (Table I bottom).

The mass of suspended solids discharged was 20.83 tons·ha^{-1} (15.29 tons inorganic and 5.54 tons organic), compared to the 12.35 tons·ha^{-1} (7.73 tons inorganic and 4.62 tons organic) that entered through pond filling and water exchanges. The respective percentages of the inorganic and organic fractions were 73.4 and 26.6% (effluent) and 62.6 and 37.4% (influent). The net exports were 8.48, 7.56 and 0.92 tons·ha^{-1}, equivalent to 68.6, 97.8 and 19.8% of the respective inputs.

The amounts of chlorophyll *a* received, discharged and exported were 0.35, 1.33 and 0.98 kg·ha^{-1} (Table I bottom). On average, the content of photosynthetic pigments of natural phytoplankton is 0.5-1.5% of its organic biomass (Becker 1994). Assuming a mean value of 1%, the respective phytoplankton loads were 35 and 133 kg·ha^{-1}and the net export was 98 kg·ha^{-1}, that represent 0.76%, 2.4% and 10.7% of the organic solids received and discharged, and of the net amount exported.

DISCUSSION

The volume of water used for pond filling and water exchanges was 206,262 m^3·ha^{-1} for the whole cycle, and rain added 2,876 m^3·ha^{-1} to the water budget. Evaporation was calculated as 13,814 m^3·ha^{-1} and, assuming no bottom losses, the water discharged during the cycle was 195,324 $m^3 \cdot ha^{-1}$, equivalent to 104.6 $m^3 \cdot kg^{-1}$ of wet shrimp biomass. The total salt input and output, calculated from the respective salinities and water volumes were 7,753 and 8,870 $tons \cdot ha^{-1}$, with a net export of 1,017 tons of $salt \cdot ha^{-1}$. This discrepancy was probably due to initial leaching of salt deposits from the previous harvest, that would explain the high salinity values of the effluent during the first half of the cycle.

Jackson *et al.* (2003) found that particulate and dissolved organic N are close to 42-45% and 37-43% of the total N wastes of shrimp farms, and their common trends may be probably explained by microalgae and bacterial uptake of the more readily available species (Burford & Glibert 1999, Burford & Williams 2001). However, in this study the relative increase in chlorophyll concentration between inlet and outlet was only 180%, in comparison to the 525% calculated for the farm evaluated by Páez-Osuna *et al.* (1997), where this high relative change and the net export of 85 $kg \cdot ha^{-1} \cdot cycle^{-1}$ of dissolved oxygen indicate active photosynthesis and vigorous phytoplankton growth.

In our case the lower relative increase of chlorophyll and the lack of a significant difference between inflow and outflows indicate that the high rates of water exchange of this farm were not convenient for its economic performance because, apart from the lower power consumption, the 3% to 6% water exchanges typical of most semi-intensive farms of NW Mexico, with consequent longer retention times, allow better nutrient utilization and plankton growth. These low water exchanges and the consequent increase in availability of natural food improves the efficiency of these farms, and explain the 9 to 29 m^3 of $water \cdot kg^{-1}$ of shrimp and the FCR values of 1.2-1.8 calculated in other semi-intensive Mexican shrimp farms (Páez-Osuna *et al.* 1997, Arispuro-Salas *et al.* 2002), in comparison to the 104.6 $m^3 \cdot kg^{-1}$ and FCR of 2.15 of the Chomojabiri farm.

This low efficiency is also a likely source of environmental impact: in this case, fertilizers and food added 281 kg N and 48.3 kg $P \cdot ha^{-1}$ to the respective water inputs and, according to Boyd & Teichert-Coddington (1995), the N and P contents of the 2,000 $kg \cdot ha^{-1}$ of head-on shrimp harvested were close to 71.5 kg N and 8.5 kg $P \cdot ha^{-1}$. These amounts represent 10.1% and 7.8% of the total inputs, in comparison to 77.5% and 68% discharged with the effluents, and are comparable to the 14% and 9% content of N and P in the shrimp biomass and the 72% and 52% discharged to the environment by other semi-intensive shrimp-farms (Teichert-Coddington *et al.* 2000).

These data confirm that the abatement of the nutrients discharged should be considered a priority for modern shrimp farming, because an increase in nutrient utilization efficiency would improve the ecological, as well as the economic performance of shrimp farms (Jackson *et al.* 2003).

According to Naylor *et al.* (1998), the low efficiency of shrimp farms is a source of environmental concern, that appears to be justified in the case of the Chomojabiri farm, that discharges its effluents in the Moroncarit lagoon. This water body is evolving into a salt marsh, it receives nutrients and suspended solids from several agricultural drains as well as through tidal exchanges and is of particular importance as a resting and feeding site for aquatic birds (http://conabioweb.conabio.gob.mx/aicas/doctos/NO-42.html). Its total volume ranges from 120,000 to 150,000 m^3 and the water exchanges estimated from the mean velocity (0.2 $cm \cdot s^{-1}$) of the tidal currents in the shallow areas of the adjacent Yavaros lagoon (Ayala-Castañares *et al.* 1980), would be at best 40-45,000 m^3, giving a mean water residence time of 3 to 5 d.

Thus, the daily discharges of 24,100 m^3 of seawater, equivalent to between 16% to 20% of the total volume of the lagoon (4.34·106 m^3 for the whole cycle, containing close to 480 t of sediments, 12.6 tons of N and 1.7 tons of P), are bound to contribute significantly to the evolution of the lagoon, as well as to its trophic status.

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REFERENCES

Arispuro-Salas N A, Armenta-Atondo S, Moreno-Martínez E 2002. Rendimiento de Litopenaeus stylirostris (Stimpson, 1874) y L. vannamei (Boone, 1931) en la granja S.C.C.P. La Clementina S C L actualmente Don Jorge, Mazatlán, Sinaloa, México. B Sc Thesis Fac Mar Sci, Autonomous Univ Sinaloa, Mazatlán, Mexico, 38 p.

Ayala-Castañares A, Malpica U M, Gutierrez M 1980. Geología marina de la región de Yavaros, Sonora, México. *An Centro Cien Mar Limnol* 7: 275-290.

Bardach J H 1997. Aquaculture, pollution and biodiversity. *In* Bardach JE Ed, Sustainable aquaculture, John Wiley and Sons, New York: 87-100.

Barg U C 1992. Guidelines for the promotion of environmental management of coastal aquaculture development. *FAO Fish Tech Pap* 328: 1-122.

Becker E W 1994. Microalgae, Biotechnology and microbiology, Cambridge University Press, 293 p.

Boyd E C, Gautier D 2000. Effluent composition and water quality standards. *Global Aquac Advocate* 5: 61-66.

Boyd C E, Teichert-Coddington D 1995. Dry matter, ash and elemental composition of pond cultured *Penaeus vannamei* and *P. stylirostris. J World Aquac Soc* 26: 88-92.

Briggs M R P, Funge-Smith S J 1994. A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquac Fish Manag* 25: 789-811.

Burford M A, Glibert P M 1999. Short-term N uptake and regeneration in early and late growth phase shrimp ponds. *Aquac Res* 30: 215-227.

Burford M A, Williams K C 2001. The fate of nitrogenous waste from shrimp feeding. *Aquaculture* 198: 79-93.

Fuchs J, Martin J L M, An NT 1999. Impact of tropical shrimp aquaculture on the environment in Asia and the Pacific. *Eur Comm Fish Coop Bull* 12(4): 9-13.

GESAMP (IMO/FAO/UNESCO-IOC/WMO/WHO/IAEA/UN/-UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) 1996. Monitoring the ecological effects of coastal aquaculture wastes, Rep Stud GESAMP 57. FAO, Rome, 43 p.

Hach 1992. Water Analysis Handbook, 2nd Ed. Hach Company, Loveland, Colorado, 831 p.

Hopkins J S, Hamilton R D, Sandifer P A, Browdy C L, Stokes A D 1993. Effect of water exchange rate on production, water quality, effluent characteristics and nitrogen budgets of intensive shrimp ponds. *J World Aquac Soc* 24: 304-320.

Jackson C, Preston N, Thompson P J, Burford M 2003. Nitrogen budget and effluent nitrogen components at an intensive shrimp farm. *Aquaculture* 218: 397-411.

Naylor R L, Goldburg R J, Mooney H, Beveridge M, Clay J, Folke C, Kautstky N, Lubchenko J, Primavera J, Williams M 1998. Nature's subsidies to shrimp and salmon farming. *Science* 282: 883-884.

Páez-Osuna F, Guerrero-Galván S R, Ruíz-Fernández A C, Espinoza-Angulo R 1997. Fluxes and mass balances of nutrients in a semi-intensive shrimp farm in North-Western Mexico. *Mar Poll Bull* 34: 290-297.

Rodier J 1981. Análisis de las Aguas, Omega, Barcelona, 1059 p.

Rosenberry B 1998. World Shrimp Farming 1998, No. 11, Shrimp News International, San Diego, California, 328 p.

SAGARPA 2004. Carta Nacional Pesquera. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Diario Oficial de la Federación, Sección IV: 33-35

Strickland J D, Parsons J R 1972. A practical handbook of seawater analysis. 2nd Ed. *Fish Res Bd Can Bull* 169: 1-310.

Teichert-Coddington D R, Martínez D, Ramírez E 2000. Partial nutrient budgets for semi-intensive shrimp farms in Honduras. *Aquaculture* 190: 139-154

Wong W H, Cheung S G 1999. Feeding behaviour of the green mussel, *Perna viridis* (L.): responses to variation in seston quantity and quality. *J Exp Mar Biol Ecol* 236: 191-207.

Zar J 1996. Biostatistical Analysis. 3rd Ed. Prentice Hall. Englewood Cliffs, 720 p.

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