Impact of low stocking densities shrimp farm effluents in water quality of a tropical coastal wetland

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Impacto de los efluentes de granjas camaroneras con baja densidad de siembra en la calidad del agua de un humedal costero tropical

Impacte dels efluents de granges de gambetes amb baixa densitat de sembrada en la qualitat de l'aigua d'un aiguamoll costaner tropical

RECEIVED: 24 MAY 2019; REVISED: 25 JULY 2019; ACCEPTED: 26 JULY 2019

SUMMARY

The effects of shrimp aquaculture on the water quality of the Jiquilisco Bay (El Salvador) was evaluated for small-scale shrimp farming with low stocking densities (≤ 12 shrimps/m^2). Two sites were selected for study: one in a concentrated shrimp farming area and the other few kilometers away without shrimp farms influence. Water samples were collected at nine different locations for spatial assessment and were taken on three occasions for temporal assessment. Parameters related to nutrient waste from shrimp farms included: biochemical oxygen demand (BOD), total suspended solids, nitrate, nitrite, dissolved phosphorus and ammonia, temperature, salinity, pH and dissolved oxygen. Effluents from shrimp farms did not exceed the limits established by regulatory norms for nitrite, nitrate, ammonia, BOD, pH and phosphorus. Significant differences for the concentrations of total suspended solids (TSS) and BOD were observed. They were higher in the channel with shrimp farms influence and always in the raining season, probably due to the drag of the rivers more than the shrimp production. It seems that at these stocking densities the carrying capacity of Jiquilisco bay was not exceeded.

Key words: Shrimp farming effluents, water quality, environmental impact, low stocking density, coastal wetland

RESUMEN

Se evaluaron los efectos de la acuicultura de camarón en pequeña escala y con baja densidad de siembra (≤ 12 camarones/m^2) en la calidad del agua de la Bahía de Jiquilisco (El Salvador). Se seleccionaron dos sitios para el estudio: uno en un área que concentra cultivo de camarón y el otro a pocos kilómetros de distancia, en un área sin influencia de las granjas camaroneras. Se recogieron muestras de agua en nueve lugares diferentes para la evaluación espacial y se tomaron en tres ocasiones para la evaluación temporal. Los parámetros relacionados con los residuos de nutrientes de las granjas camaroneras incluyeron: demanda bioquímica de oxígeno (DBO), sólidos en suspensión total, nitrato, nitrito, fósforo y amoníaco disueltos, temperatura, salinidad, pH y oxígeno disuelto. Los efluentes de las granjas camaroneras no excedieron los límites establecidos por las normas reglamentarias para nitritos, nitratos, amoníaco, DBO, pH y fósforo. Se observaron diferencias significativas para las concentraciones de sólidos suspendidos totales (TSS) y DBO. Fueron más altas en el canal con influencia de las granjas camaroneras y siempre en la temporada de lluvias, probablemente debido al arrastre de los ríos más que a la producción de camarón. Parece que a estas densidades de siembra no se excede la capacidad de carga de la bahía de Jiquilisco.

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Palabras clave: Efluentes del cultivo de camarón, calidad del agua, impacto ambiental, baja densidad de siembra, humedal costero.

RESUM

Es van avaluar els efectes de l'aqüicultura de gambeta a petita escala i amb baixa densitat de sembrada (≤ 12 gambetes/m^2) en la qualitat de l'aigua de la Badia de Jiquilisco (El Salvador). Es van seleccionar dos llocs per a l'estudi: un en una àrea que concentra cultiu de gambeta i l'altre a pocs quilòmetres de distància, en una àrea sense influència de les granges de gambetes. Es van recollir mostres d'aigua en nou llocs diferents per a l'avaluació espacial i es van prendre en tres ocasions per a l'avaluació temporal. Els paràmetres relacionats amb els residus de nutrients de les granges de gambetes incloïen: demanda bioquímica d'oxigen (DBO), sòlids en suspensió total, nitrat, nitrit, fòsfor i amoníac dissolts, temperatura, salinitat, pH i oxigen dissolt. Els efluents de les granges de gambetes no van excedir els límits establerts per les normes reglamentàries per nitrits, nitrats, amoníac, DBO, pH i fòsfor. Es van observar diferències significatives per a les concentracions de sòlids suspesos totals (TSS) i DBO. Van ser més altes al canal amb influència de les granges de gambetes i sempre en la temporada de pluges, probablement a causa de l'arrossegament dels rius més que a la producció de gambeta. Sembla que a aquestes densitats de sembrada no s'excedeix la capacitat de càrrega de la badia de Jiquilisco.

Paraules clau: Efluents del cultiu de gambeta, qualitat de l'aigua, impacte ambiental, baixa densitat de sembrada, aiguamoll costaner

INTRODUCTION

There is concern on the potential negative environmental impacts of shrimp aquaculture [1–5]. The main reported impacts are destruction of mangroves, overexploitation of wild post larvae for pond stocking and contamination of water bodies with nutrients, organic matter and sediments discharged to coastal ecosystems when ponds are drained.

The temporal and spatial scale of such impacts, however, vary considerably depending on farm management practices, e.g. the number, scale and proximity of shrimp farms, farm flushing rates as well as the carrying capacity of the receiving water bodies [5,6].

Many authors used different sampling designs to assess the influence of shrimp discharges in the water quality of the adjacent receiving water bodies [6–12].In those studies different sampling sites were selected for spatial assessment of water quality, usually including the effluent discharge sites and the channel or tidal creek that receives the effluents directly. In some cases reference sites or control stations located a few kilometers away in areas of no shrimp cultivation are included. These control stations allows to monitoring the influence of other contributions, such as fluvial discharge and runoff from agriculture areas, in water quality [6,9,10,12].

Table 1 summarizes the shrimp farm sizes and the stocking densities used in some pond areas that have been previously studied to determine the discharge impact on the water quality of adjacent water bodies. The stocking densities of the studies vary between 15 and 70 shrimps/m^2 with an average of 30 shrimps/m^2. Accordingly, there is a lack of information on sites with low stocking densities (less than 12 shrimps/m^2).

Aquaculture in Central America has grown by 198% in the last decade, with an annual average of 81565 tons, of which 65% corresponds to marine shrimp culture [16]. However, production remains low compared with world production which was 66.6 million tons in 2012 with Asia as main producer [17].

Shrimp farming in Central America is essentially industrial with commercial links with small-scale growers. In this context, El Salvador is an exception because since 2000 onwards there are no active industrial producers or private economic groups, only cooperatives and other small-scale associations [18]. El Salvador accounts for 0.54% of shrimp production in the region; this activity represents a source of income, food and employment for many low-income families. These small-scale producers are vulnerable to external drivers:

Table 1. *Other studies farm sizes and stocking densities*

Country	Area of aquaculture park studied	Stocking density (shrimps/m^2)	Reference
Australia	13.5 ha	25-35	(Wolanski et al., 2000)
Australia	6 ha	35	(Jones et al., 2001)
Australia	29 ha	25-35	(Costanzo et al., 2004)
Eastern China	287 ha	60-70	(Biao et al., 2004)
New Caledonia	133 ha	15-21	(Thomas et al., 2010)
	30 ha	29-39	
New Caledonia	18 ha	17	(Molnar et al., 2013)
México	250 ha	20	(Cardoso-Mohedano et al., 2016)
Tanzania	24 ha	15-20	(Mateka, 2015)

such as climate change, market demands, feed price and other factors which are largely out of their control [5].

Eighty-seven percent of the marine shrimp growing (*Penaeus vannamei*) in El Salvador is focused on the area of the eastern lower bank of the Lempa river and Jiquilisco Bay with a production area of 723 ha in 2013 [18]. Most shrimp farms located in this area have been developed from former salt evaporating ponds, which were transformed with the support of the European Union in a project for the reintegration of ex-combatants of the civil war [19].

In Fig 1, the eight zones devoted to the cultivation of marine shrimp in Jiquilisco Bay are shown. There are 32 shrimp producers, 28 belonging to cooperative associations and five to individual producers [20]. They follow three cropping patterns. The first one, extensive (23%) with a production of 181.4 kg/ha per cycle and a stocking density of 5-6 shrimps/m^2. The second one, extensive improved (32%) with 589.7 kg/ha per cycle and a stocking density of 5-8 shrimps/m^2. And the third one, semi-intensive (45%) with 816.5 to 997.9 kg/ha per cycle and a stocking density of 10-20 shrimps/m^2 [18,20]. Comparing to the farming sites of Table 1, the stocking densities in El Salvador are low, even for semi intensive operation. Therefore, they provide good cases to study the impacts on the water quality of the receiving creek for this size of culture.

Fig 1 *Location of marine shrimp farming in the Jiquilisco Bay*

The present study is therefore devoted to examine the effluent loads from shrimp farms with low stocking densities and its influence on the water quality of Jiquilisco Bay. For this purpose, three different sites were studied, one directly influenced by shrimp farm activity, another without influence of this activity and the last at the discharge gates of 5 ponds located in the channel influenced by shrimp farming. All sites were under the same watershed influence, particularly in the rainy season. During the present study, the stocking density in the studied sites was never above 12 shrimps/m^2.

The reported results in this paper are part of a work project with the shrimp farming sector of the Jiquilisco Bay that lasted from 2008 to 2015. Data were gathered during 2009.

MATERIALS AND METHODS

Studied Area

The studied shrimp area was El Zompopero (Jiquilisco Bay; 13°13′N and 88°30′O) (Fig. 2). This bay is a wetland of significant ecological value because it concentrates the largest area of national mangrove. It was recognized as a Ramsar site in 2005 and as an international Biosphere Reserve zone in 2007 by UNESCO. Five ponds, named El Muelle, La Carranza, El Torno, La Bomba 1 and La Bomba 2 (Fig 2a) were monitored from February to December 2009 to measure the water quality of the discharged water.

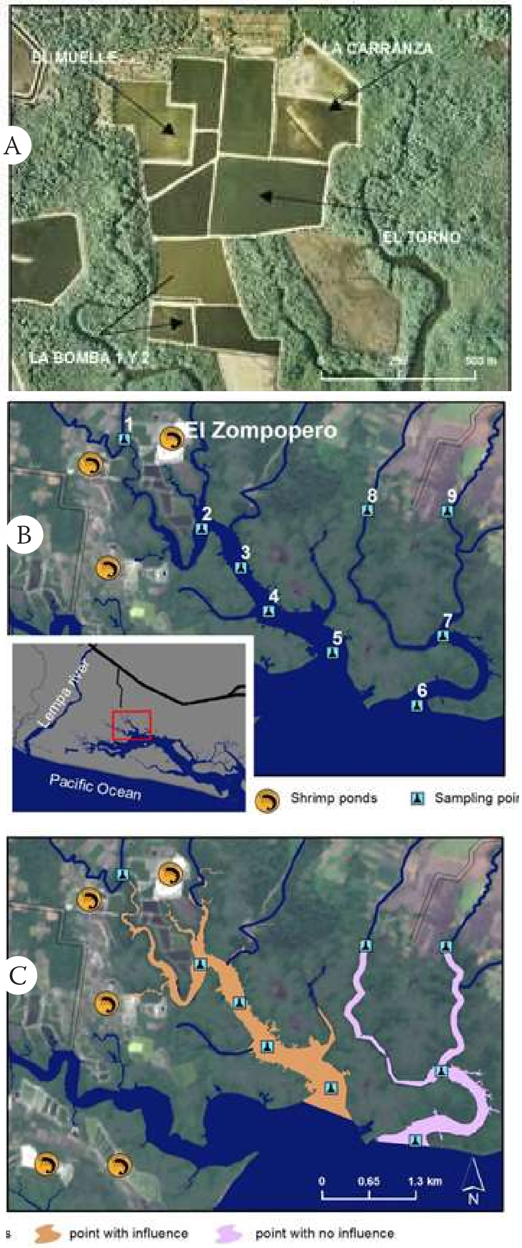

Fig 2 *a) Monitored shrimp pond; b) Location of sampling sites in the bay; c) Selected zones with and without shrimp influence*

Table 2 shows the characteristics of the entire growing cycle (n=10) during the study period. Stocking density was always below 12 post larvae

Table 2. *Characteristics of each pond and the characteristics of each crop*

Shrimp pond	Period of production	Pond area (m^2)	Stocking density (post larvae/m^2)	Feed	Origin of post larvae	Water Exchange
El Muelle	April-July	57000	8.8	Artificial	Wild- caught	Tidal
El Muelle	July-September	57000	10.5	Artificial	Wild- caught	Tidal
El Muelle	October-December	57000	10.5	Artificial	Wild- caught	Tidal
La Bomba 1	May-August	55000	10.9	Artificial	Hatchery	Tidal
La Bomba 1	September-December	55000	4.6	Artificial	Wild- caught	Tidal
La Bomba 2	September-December	40000	10	Artificial	Wild- caught	Pump
El Torno	February-May	75000	11	Artificial	Hatchery	Pump
El Torno	June-August	75000	12	Artificial	Hatchery	Pump
El Torno	September-December	75000	6.7	Artificial	Hatchery	Pump
La Carranza	June-July	40000	2.9	Natural	Wild- caught	Tidal

Table 3 *Variation of parameters in all cycles of cultivation pond*

						Limit Values		
	El Muelle	**La Bomba 1**	**La Bomba 2**	**El Torno**	**La Carranza**	**GAA norm. Initial values**	**GAA norm. After 5 year**	**CONACYT Norm**
Number of samples	30	21	6	29	7			
OD6 (mg/L)	4.5 ±1.3	3.5±1.6	3.6±1.1	5.2±1.5	6.8±1.1	[b]	[b]	[b]
pH (mg/L)	8.2±0.3	8.4±0.3	8.1±0.2	8.5±0.3	8.6±0.2	6.0-9.5	6.0-9.0	5.5-9.0
Temperature (°C)	32.1±1.3	31.4±1.6	30.6±1.6	31.9±1.1	31.8±0.9	[b]	[b]	[b]
Secchi disk (cm)	43±11	36±10	38±6	44±9	60±0	[b]	[b]	[b]
Salinity (‰)	25.9±6.4	23.7±3.2	21.5±1.7	27.9±6.7	26.2±1.1	[b]	[b]	[b]
Number of samples	14	11	5	12	4			
Ammonia (mg/L)	0.7±1.2	0.3±0.8	0.03±0.03	0.05±0.04	0.09±0.08	5.0	3.0	[b]
Nitrate (mg/L)	0.2±0.3	0.03±0.09	0.004±0.007	0.009±0.009	0.009±0.01	[b]	[b]	[b]
Nitrite (mg/L)	0.002±0.006	0.01±0.01	0.008±0.01	0.004±0.006	0.004±0.008	[b]	[b]	[b]
Dissolved Phosphorus (mg/L)	0.005±0.01	0.01±0.02	ND	0.01±0.03	0.01±0.02	0.5	0.3	[b]
Total Suspended Solids (mg/L)	158±246	120±128	15.4±14	75±160	70±48	100	50	150
BOD (mg/L)	5.4±2.6	7.3±2.8	6.8±3.2	6.7±3.0	6.3±2.8	50	30	300[a]

[a] limits for agricultural production; [b] no limits reported

per square meter. During this period, 60% of post larvae used were wild-caught. Nowadays the use of this type of post-larvae is not widely used. Commercial feed (30% protein) was added to ponds with inputs that increased as shrimp grew. Water exchange from ponds varied according to the stage of growth cycle, ranging from 0% in the first stocking month up to 25% volume in the final growth stages. Water was taken from a natural tidal-creek and is discharged into the same creek on low tide.

Sampling and measurements

Shrimp ponds effluents

Water samples were taken every two weeks at the site of water discharge during the shrimp production season. Forty-four water samples were collected near the surface. These samples were used to measure biochemical oxygen demand (BOD), total suspended solids (TSS), nitrate, nitrite, dissolved phosphorus and ammonia ($N\text{-}NH_3$) using standard methods [21].

At each pond, during the production season, measurements of temperature, dissolved oxygen (YSI field oxygen meter 85), water transparency with a Secchi disc, and pH (OAKTON, pH11) were done every other day at 06:00, 12:00 and 18:00 h.

Jiquilisco Bay

Two different tidal-creeks were selected in Jiquilisco Bay for the study, one (orange zone in Fig 2c) in a concentrated shrimp farming area and the other (pink zone in Fig 2c) a few kilometers away without shrimp farming influence. In both areas, there were similar releases of freshwater runoff and the extent of mangrove forest was similar (Fig 2b).

As shown in Fig 2b, site 1 is on the channel that supplies water to El Zompopero shrimp ponds and receives water from a river. Sites 2, 3, 4 and 5 are located along the channel of the bay that supplies brackish water. This channel also receives effluent water from El Zompopero shrimp ponds. Sampling sites 6, 7, 8 and 9 are placed in a channel without shrimp farming activity and site 9 also receives water from a river. Shrimp culturing encompass the main difference between the two zones because the small rivers are under the influence of the same agricultural area.

Water samples were collected in 2009 in April (dry season), August (raining season) and December (transition season). Sampling was performed with an horizontal Van Dorn sampler, equipped with 2.5 L plastic bottles. These bottles were immediately labeled and stored on ice. These samples were used to measure the same variables as water taken from shrimp ponds: biochemical oxygen demand (BOD), total suspended solids (TSS), nitrate, nitrite, dissolved phosphorus and ammonia ($N\text{-}NH_3$) following APHA standard methods [21]. At selected intake sites, in situ pH, temperature and dissolved oxygen were determined.

Data Analysis

A variance analysis considering the sampling sites and yearly period was performed. The Statistical Package for Social Sciences Windows version 13.0 (SPSS) was used at a significance level of 0.05 for this purpose.

RESULTS AND DISCUSSION

Measurements in shrimp ponds effluents

Table 3 shows the averages and standard deviations of the studied water physicochemical parameters in a shrimp pond during all production cycles. In all these tables, OD6 means, "dissolved oxygen measured at 6:00 a.m." and ND means "not detected", it also shows the accepted limits for the same variables analyzed in the study for two accepted norms. The Global Aquaculture Alliance (GAA) with the present accepted limits (first column), the GAA with the objective limits to be achieved after 5 years (second column) [22] and El Salvador's norm for residual water discharged in a reservoir [23], more permissive than the GAA norm.

The average temperature in the discharge water ranged between 30.6 and 32.1°C, these values are consistent with those observed in other tropical ecosystems and within the desired range of 25-32°C for normal growth and survival of aquatic organisms in tropical environments [15,24].

The measured pH values were always up to 7.2 and below 8.7, except in the 10th week of the second grow in the El Torno pond with a value of 9.1. All these values, except one, were always in the accepted range for pH by GAA and CONACYT norms and within the desired range of 7-9 for normal growth [24,25]. The exception is not far from maximum value and can be corrected easily. As it is reported by other authors, pH values tend to increase during cultivation due to the liming of the pond at the beginning of the crop and to phytoplankton photosynthesis [7,15,26].

All ammonia values were below the limit proposed as objective for GAA norm (3 mg/L), the average values were between 0.03-0.7 mg/L. Other studies in shrimp ponds showed ammonia average values in wastewater of 0.5-0.7 mg/L [27] or 0.1-0.3 mg/l [12]. These values are similar to the average measurements in El Muelle and La Bomba but higher than those in the rest of ponds analyzed. Considering all individual measurements, only one, 3.8 mg/L, that corresponds at the 6th week of the first grow at El Muelle pond, was above limit recommendations. Dissolved inorganic phosphorus was always below the accepted limit in the GAA norm, even its objective in five years.

All BOD values were below 7.6 mg/L far below the limit established as objective for the GAA norm, 30 mg/L, and even lower than the Salvadorian norm (CONACYT, 2009). The measured values were also lower than those reported in other studies. For example, in an intensive crop in Vietnam, with a stocking density higher than 20 post larvae/m², they were between 8 and 59 mg/L for BOD.

Some of the values obtained for total suspended solids were over the accepted limits by the two norms. In particular, in one week in the El Torno pond crop and during the firsts crops in El Muelle and La Bomba ponds (Fig 3). However, only the average of total suspended solids in El Muelle crops were higher than the limit stablished by the considered norms.

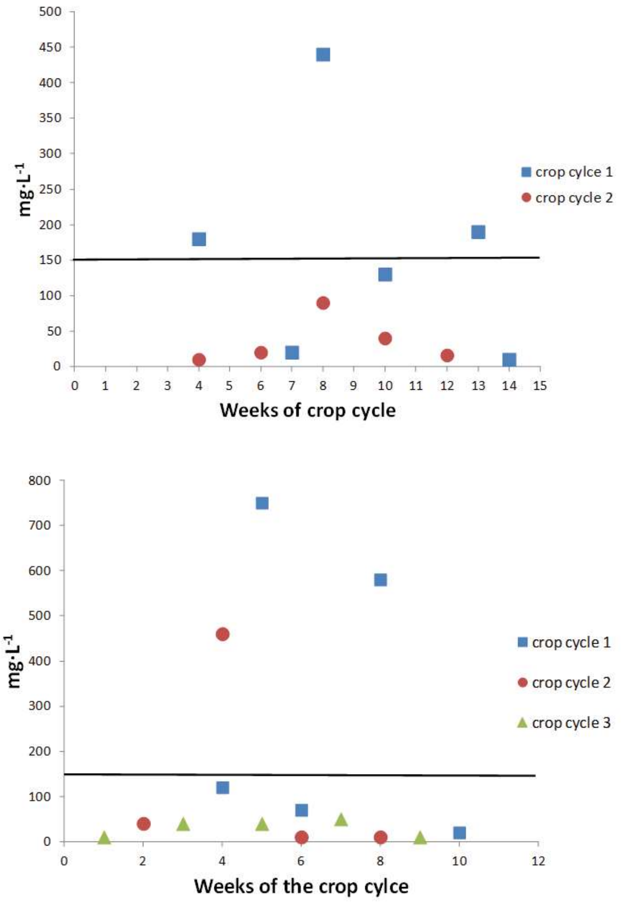

Fig 3 *Weekly concentrations of total suspended solids at Shrimp pond effluents of crop cycle in a) La Bomba pond and b) El Muelle pond.*

The high levels of total suspended solids detected during those crops may be related to the big excess of feed was added after 6 weeks of growing (Fig 4) as it is suggested by some authors [2,4,28–30]. When this practice was corrected, crop cycle 2 of La Bomba and crop cycle 2 and 3 in El Muelle, all measurements of suspended solids were below permitted limits.

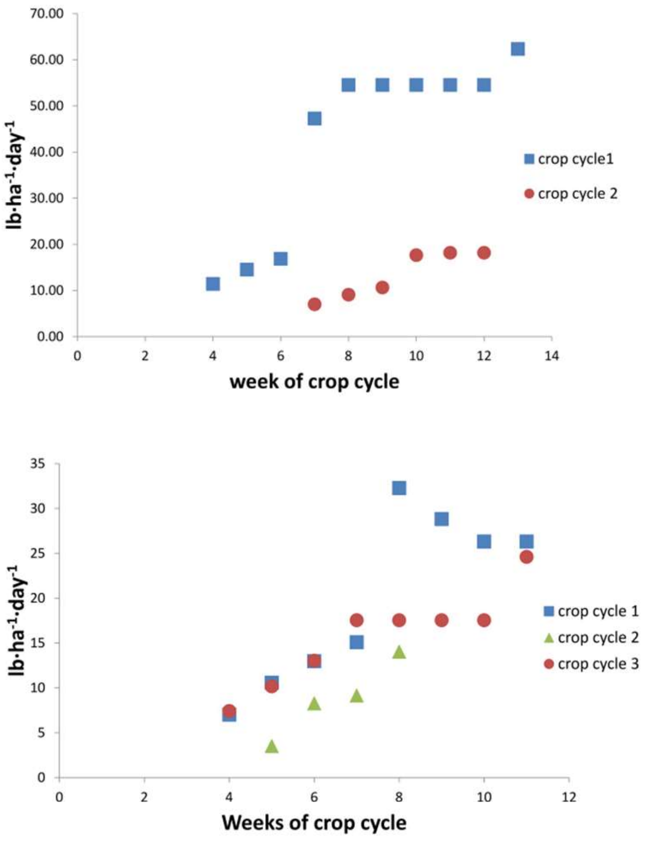

Fig 4 *Amount of feed in lb·ha^{-1}·day^{-1} every week of crop cycle in a) La Bomba pond and b) El Muelle pond*

In any case, the values of total suspended solids in the studied crops were lower than those reported in other studies. For example, in an intensive crop in Vietnam, with a stocking density higher than 20 post larvae/m^2, they ranged between 26 and 1031 mg/L with an increase at the end of the production cycle [27], in Kino Bay (Mexico) values of suspended solids in the discharge waters were of 233.2 ± 95.7 mg/L [10]. This study does not report the stocking densities of their ponds, but Kino Bay concentrates 37% of the production of marine shrimp from Mexico that produces 110000 tons/year [10]. Comparing this figure with the production of El Salvador, 3216 tons in 2010 [16] shows that the studied area in this work has less intensity of cultivation.

Measurements in the bay

Fig 5 shows the average values of the three water levels (superficial, middle and bottom) sampled at every site in the bay during the various sampled months. In the sites near the mouth of the rivers (1, 2, 8 and 9) it was not always possible to sample all three levels because of the low water depth. In these cases, only one or two samples were taken.

During the development of this work, national water quality values were not available to compare with the obtained results. The data found in this study could be taken as reference for further studies in the Jiquilisco Bay area.

Ammonia

The analysis of variance showed that the variation of the concentrations of ammonia due to location, seasonal changes and sampling depth were statistically significant (P<0.05). The factors with more impact were the location and the season of sampling. The concentration of ammonia in the bay varied from 0.02 to 3.30 mg/L (Table 4), the highest values were measured in the dry season (Fig 5) and only in this season exceed the Marine Water Quality Criteria for Asian Region (<0.07 mg/L). Ammonia in water is the principal nitrogenous waste product excreted by aquatic animals and released from decomposing nitrogen containing organic matters by microbial activities; it is assimilated by algae or transformed into nitrite and then nitrate forms in the water column [25]. Accumulation of ammonia may have resulted from low flushing rate and poor agitation effect during the dry season [6], and specially in site 5 (Fig 5).

Nitrite and Nitrate

Nitrite and nitrate are products of nitrification processes in water, where aerobic chemoautotrophic bacteria oxidizes ammonia. Nitrite exists at low levels since it is usually converted into nitrate. As seen in Table 4, the concentration of nitrite in the bay was generally low (<0.05 mg/L) and at all times below the standard (<0.055 mg/L). In the dry season, the presence of nitrite was only detected at sites 1 and 7 (Fig 5), with the concentration of site 1 being the highest of all cases. In both sites, it was observed that in dry season, and at low tide, the water level was very low and the bottom sediment very reducing. In these conditions, a strong smell of hydrogen sulfide was perceived. Possibly, this reducing environment was the cause of accumulation of nitrites in these areas during the dry season. In the rainy and transition seasons it was observed that the sites near the river mouths had higher concentrations of nitrites and that this concentration decreased as the sampling sites approached the bay. The analysis of variance showed that the spatial variation in these seasons was statistically significant (P<0.05). As observed in Table 4, the concentrations of Nitrate in the bay varied from 0.001 to 1.5 mg/L, and were highest in the dry season. Only during this season, the concentration of this anion exceeded the Marine Water Quality Criteria for Asian Region (<0.06 mg/L). Since no nitrite was present in that season, it can be stated that ammonia was oxidized entirely. Only in the dry season the concentration of nitrite exceeded the norm for sites 1 and 7 and 9 for nitrate (Fig 5), all these sampling sites are not under the influence of water discharges from shrimp farms.

Phosphate

The concentration of phosphate ranged between 0.03 and 0.17 mg/L (Table 4), exceeding in many sites

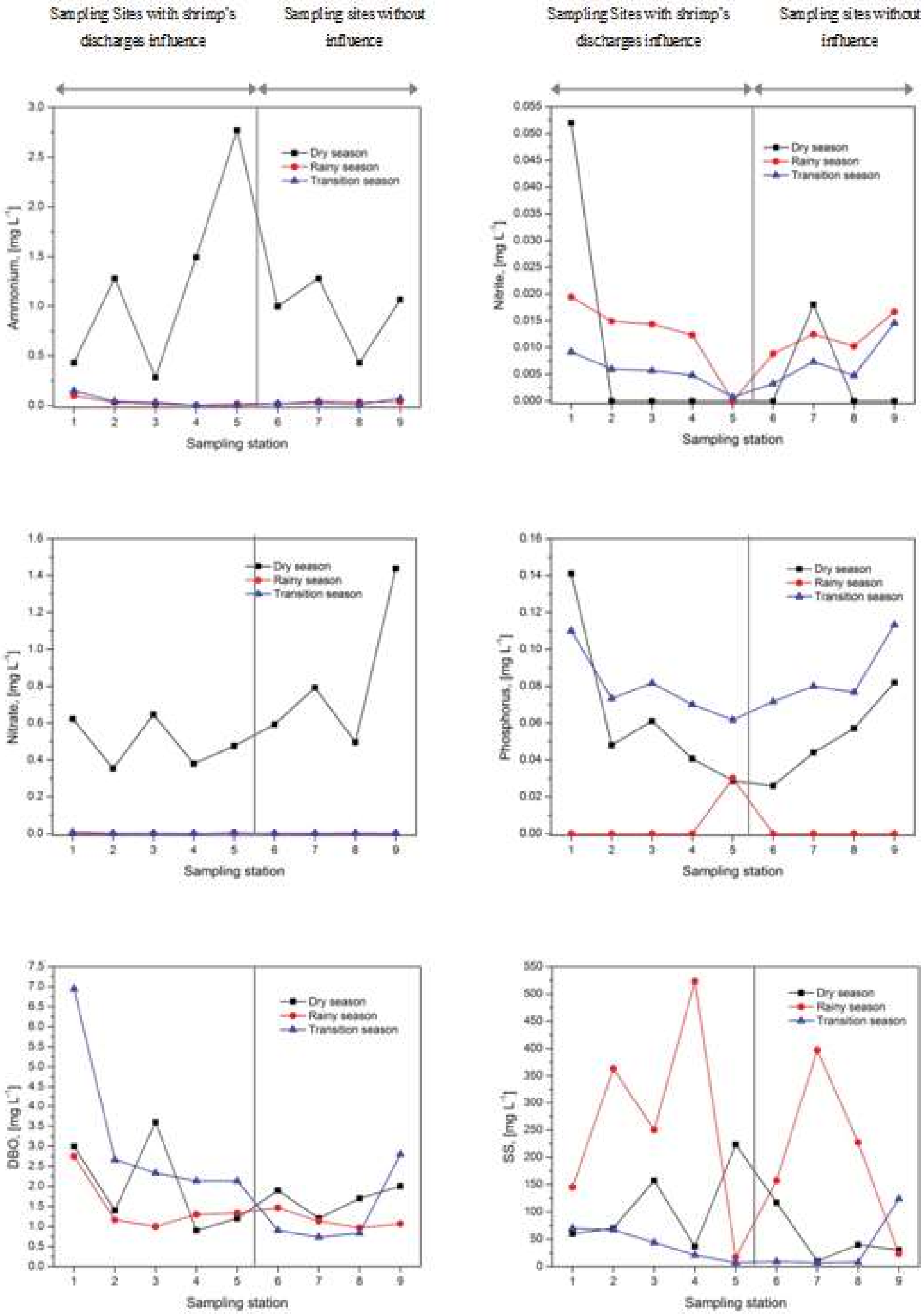

Fig 5 *Variation of the measured parameters in all sampling sites of the bay.*

Table 4. *Characteristic water values in the Jiquilisco Bay*

Variables	Minimum measured	Maximum measured
pH	6.8	7.8
Total solids (g/L)	13	55
Total Suspended Solids (mg/L)	7	550
Ammonia (mg/L)	0.02	3.30
Nitrite (mg/L)	0.001	0.05
Nitrate (mg/L)	0.001	1.5
Phosphate (mg/L)	0.03	0.17
Dissolved oxygen (mg/L)	1.8	5.9
BOD (mg/L)	0.73	7.0
Salinity (ppt)	11	33
Temperature (ºC)	26	38
Turbidity (Secchi disc, cm)	28	220

the standard (<0.045 mg/L). The analysis of variance showed that the spatial and temporal variation of the phosphate concentration was statistically significant ($P<0.05$). The concentration of this anion was higher in the transition season (Fig. 5) followed by the dry season. In both seasons a similar behavior in the concentration of nitrites was observed. The concentrations were higher in the sites near river discharges (sites 1, 9), which could be explained by the nutrient load in river discharges and watershed runoff. This is consistent with the results of Mateka [15] and Wu [33]: they reported that the effects of effluents usually are concentrated in the first 2 km from the discharge sites. Nevertheless, in the present case, the discharges were not under the influence of the shrimp farm effluents, but of the discharges of the rivers into the bay.

Biochemical Oxygen Demand (BOD)

BOD represents the oxygen consumption from bacterial degradation of organic material in water, Boyd and Green [31] suggested that it should be below 6 mg/L for protecting coastal aquatic ecosystems. In this study, it was between 0.73 and 7.00 mg/L and only exceeded the safe value in the transition season in site 1 located in the river discharge. In this site the highest values were recorded and they were also high in the other two seasons.

Total Suspended Solids (TSS)

TSS indicates the concentration of suspended soil particles and suspended organic matter. The Marine Quality standard stands that the TSS must be under 50 mg/L. In this study, TSS varied between 5 and 550 mg/L (Table 4), similar wide variations are also reported by other authors [6]. The values exceed the standard especially in rainy season (Fig 5). It is possible that heavy rains mobilize sediments and runoff increases the input of particulate material in the bay.

Influence of the shrimp ponds in the bay

To evaluate the effect of the shrimp ponds, data were grouped in two sets. One containing all the values from sites 1 to 5 (Fig 2b) that were influenced by the shrimp ponds discharged water, and values from sites 6 to 9 (Fig 2b) without shrimp pond influence. Analysis of variance for ammonia, inorganic phosphorus, and nitrite and nitrate showed that the differences of concentration of these compounds in both sites were not statistically significant ($P > 0.05$) which led to conclude that the discharges of shrimp farms were not significant. The same was observed for the concentration of total solids. The discharges from the shrimp ponds did not alter the concentration of total solids that were apparently dominated by salt water.

The difference of the BDO values between the two arms was statistically significant ($P < 0.05$). An interaction between the sampling month and sample grouping was observed. As mentioned above, sampling site 1 showed the highest BOD values (Fig. 5), reflecting an increment of BOD values in sites located downstream. Despite this difference, BOD values in the water discharged from shrimp farms were always below the regulatory limits. BDO could be due to trawls of river organic matter from inhabited and agricultural areas more than from the shrimp farms themselves. This is consistent with what was found in a similar environment in the neighboring country of Honduras, the water quality from the estuary near the Gulf of Fonseca region, where a lot of shrimp activity is found, was directly and mainly influenced by the discharges of rivers and watershed runoff [31].

The analysis of variance of the concentration of total suspended solids, between the channel with shrimp ponds and the channel without them, showed that the difference in the concentration was statistically significant ($P < 0.05$). Global average of total suspended solids concentration and Secchi disk reading in each sampling site (Fig 6) were higher in the channel with shrimp ponds but always high during the raining season (August). Such turbidity may result from primary productivity, as well as from the turbulence created at higher river flow. This observation was in agreement with the results reported by Bui et al. in 2012 and Anh et al. in 2012 [6,26].

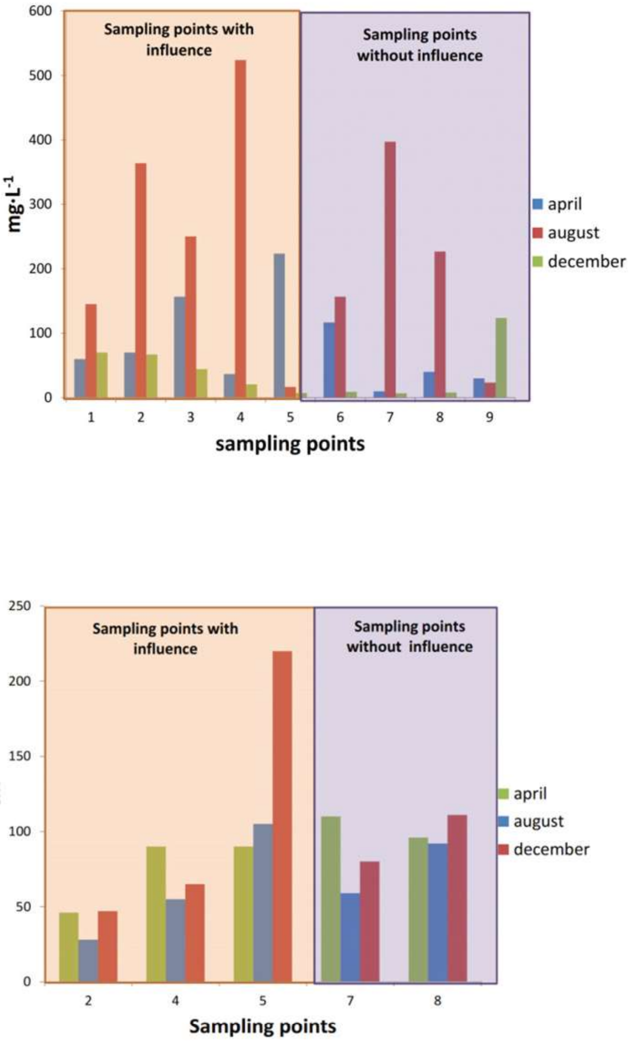

Fig 6 *Total suspended solids and Secchi disk readings from the sampling sites in the three studied months*

CONCLUSIONS

Water discharges from shrimp farms did not exceed the limits established by regulatory norms of receiving body discharges for nitrite, nitrate, ammonia, total solids, BOD, pH, and phosphate. Only the average of suspended solids concentration exceeded these limits in two crops. In these crops the amount of food supplied per day per hectare was higher than in the others, which suggest that these parameters are related and better food handling could reduce the total suspended solids in the discharges.

The discharges of water from shrimp ponds did not have significant influence in the concentration of ammonia, nitrite, nitrate, phosphate and total solids in the bay. Furthermore, a significant difference was found in the concentrations of suspended solids and BOD being higher in the channel with shrimp farms influence. Assessment of these parameters in discharge sites from shrimp farms showed that the suspended solids were outside the norm only in two of the monitored crops and always in the raining season, probably due to the drag of the rivers instead of the shrimp production.

The results of this study suggest that the concentration of crops in the Jiquilisco Bay are low enough so that this activity does not affect the water quality of the bay. Similar results have been reported in other studies in tropical ecosystems [15,32,33]. At these stocking densities, the carrying capacity of Jiquilisco bay was not exceeded. If this stocking densities are maintained, this productive system is a sustainable economic input and a source of protein for families that are living in the region, contributing to their social-economic development.

ACKNOWLEDGMENTS

This research was funded by Fondo de la Iniciativa para las Américas (FIAES) and is part of the PhD dissertation of M. D. Rovira done under the program at the IQS and the UNESCO Chair both from the Ramon Llull University.

REFERENCES

1. Lemonnier, H.; Faninoz, S. Effect of Water Exchange on Effluent and Sediment Characteristics and on Partial Nitrogen Budget in Semi-Intensive Shrimp Ponds in New Caledonia. *Aquac. Res.* **2006**, *37* (9), 938–948. https://doi.org/10.1111/j.1365-2109.2006.01515.x.
2. Martin, J.-L. M.; Veran, Y.; Guelorget, O.; Pham, D. Shrimp Rearing: Stocking Density, Growth, Impact on Sediment, Waste Output and Their Relationships Studied through the Nitrogen Budget in Rearing Ponds. *Aquaculture* **1998**, *164* (1–4), 135–149. https://doi.org/10.1016/S0044-8486(98)00182-3.
3. Teichert-Coddington, D. R.; Rouse, D. B.; Potts, A.; Boyd, C. E. Treatment of Harvest Discharge from Intensive Shrimp Ponds by Settling. *Aquac. Eng.* **1999**, *19* (3), 147–161. https://doi.org/10.1016/S0144-8609(98)00047-8.
4. Paez-Osuna, F. The Environmental Impact of Shrimp Aquaculture: Causes, Effects, and Mitigating Alternatives. *Environ. Manage.* **2001**, *28* (1), 131–140. https://doi.org/10.1007/s002670010212.
5. White, P.; Phillips, M.; Beveridge, M. C. M. Environmental Impact, Site Selection and Carrying Capacity Estimation for Small-Scale Aquaculture in Asia. *Site Sel. Carr. Capacit. Inl. Coast. Aquac.* **2013**, 231.
6. Bui, T. D.; Luong-Van, J.; Austin, C. M. Impact of Shrimp Farm Effluent on Water Quality in Coastal Areas of the World Heritage-Listed Ha Long Bay. *Am. J. Environ. Sci.* **2012**, *8* (2), 104–116. https://doi.org/10.3844/ajessp.2012.104.116.
7. Biao, X.; Zhuhong, D.; Xiaorong, W. Impact of the Intensive Shrimp Farming on the Water Quality of the Adjacent Coastal Creeks from Eastern China. *Mar. Pollut. Bull.* **2004**, *48* (5–6), 543–553. https://doi.org/10.1016/j.marpolbul.2003.10.006.
8. Cardoso-Mohedano, J. G.; Paez-Osuna, F.; Amezcua-Martinez, F.; Ruiz-Fernandez, A. C.; Ramirez-Resendiz, G.; Sanchez-Cabeza, J. A. Combined Environmental Stress from Shrimp Farm and Dredging Releases in a Subtropical Coastal Lagoon (SE Gulf of California). *Mar. Pollut. Bull.* **2016**, *104* (1–2), 83–91. https://doi.org/10.1016/j.marpolbul.2016.02.008.
9. Molnar, N.; Welsh, D. T.; Marchand, C.; Deborde, J.; Meziane, T. Impacts of Shrimp Farm Effluent on Water Quality, Benthic Metabolism and N-Dynamics in a Mangrove Forest (New Caledonia). *Estuar. Coast. Shelf Sci.* **2013**, *117*, 12–21. https://doi.org/10.1016/j.ecss.2012.07.012.
10. Barraza-Guardado, R. H.; Martinez-Cordova, L. R.; Enriquez-Ocana, L. F.; Martinez-Porchas, M.; Miranda-Baeza, A.; Porchas-Cornejo, M. A. Effect of Shrimp Farm Effluent on Water and Sediment Quality Parameters off the Coast of Sonora, Mexico Efecto de Efluentes de Granjas Camaron{í}colas Sobre Par{á}metros de La Calidad Del Agua y Del Sedimento Frente a La Costa de Sonora, M{é}xico. *Ciencias Mar.* **2014**, *40* (4), 221–235.
11. Thomas, Y.; Courties, C.; El Helwe, Y.; Herbland, A.; Lemonnier, H. Spatial and Temporal Extension of Eutrophication Associated with Shrimp Farm Wastewater Discharges in the New Caledonia Lagoon. *Mar. Pollut. Bull.* **2010**, *61* (7–12), 387–398. https://doi.org/10.1016/j.marpolbul.2010.07.005.
12. Costanzo, S. D.; O'Donohue, M. J.; Dennison, W. C. Assessing the Influence and Distribution of Shrimp Pond Effluent in a Tidal Mangrove Creek in North-East Australia. *Mar. Pollut. Bull.* **2004**,

48 (5), 514–525. https://doi.org/10.1016/j.marpolbul.2003.09.006.
13. Wolanski, E.; Spagnol, S.; Thomas, S.; Moore, K.; Alongi, D. M.; Trott, L.; Davidson, A. Modelling and Visualizing the Fate of Shrimp Pond Effluent in a Mangrove-Fringed Tidal Creek. *Estuar. Coast. Shelf Sci.* **2000**, *50* (1), 85–97. https://doi.org/10.1006/ecss.1999.0535.
14. Jones, A. .; Dennison, W. .; Preston, N. . Integrated Treatment of Shrimp Effluent by Sedimentation, Oyster Filtration and Macroalgal Absorption: A Laboratory Scale Study. *Aquaculture* **2001**, *193* (1–2), 155–178. https://doi.org/10.1016/S0044-8486(00)00486-5.
15. Mateka, H. A. Study on the Water Quality Parameters in Semi-Intensive Coastal Shrimp Culture System in Mafia Island , Tanzania. *J. Environ. Earth Sci.* **2015**, *5* (1), 142–151.
16. Beltran, `Claudia Stella. Contribución de la pesca y la acuicultura a la seguridad alimentaria y el ingreso familiar en Centroamérica http://www.racua.org/uploads/media/Estado_actual_pesca_acuicultura_Centroamerica_-_FINAL.pdf (accessed Oct 30, 2014).
17. FAO. El estado mundial de la pesca y la acuicultura 2014 http://www.fao.org/3/a-i3720s/index.html (accessed Sep 9, 2015).
18. Oddone, N.; Beltran, S. *CEPAL - Diagnóstico de la cadena de camarón de cultivo en El Salvador*; 2014.
19. FAO. FAO Fisheries & Aquaculture - Visión general del sector acuícola nacional - El Salvador http://www.fao.org/fishery/countrysector/naso_elsalvador/es (accessed Sep 22, 2015).
20. Hernández-Rauda, R.; López, W.; Vasquez-Jandres, M. *El Cultivo Del Camarón Marino En La Bahía de Jiquilisco, Usulután, El Salvador*; 2006.
21. APHA. *Standard Methods for the Examination of Water and Wastewater | Clc*; 2012.
22. Global Aquaculture Alliance. *Finfish and Crustacean Farms BAP Standards, Guidelines*; 2014.
23. CONACYT. *NORMA SALVADOREÑA CONACYT NSO 13.49.01:06 "AGUA. AGUAS RESIDUALES DESCARGADAS UN CUERPO RECEPTOR";* 2009.
24. Boyd, C.; Pillai, V. Water Quality Management in Aquaculture. *C. Spec. Publ.* **1985**, *22*, 1–44.
25. Boyd, C. E.; Tucker, C. S. Water Quality and Aquaculture: Preliminary Considerations. In *Pond Aquaculture Water Quality Management*; Springer US: Boston, MA, 1998; pp 1–7. https://doi.org/10.1007/978-1-4615-5407-3_1.
26. Anh, P. T.; Kroeze, C.; Bush, S. R.; Mol, A. P. J. Water Pollution by Intensive Brackish Shrimp Farming in South-East Vietnam: Causes and Options for Control. *Agric. Water Manag.* **2010**, *97* (6), 872–882. https://doi.org/10.1016/j.agwat.2010.01.018.
27. Anh, P. T.; Kroeze, C.; Bush, S. R.; Mol, A. P. J. Water Pollution by Intensive Brackish Shrimp Farming in South-East Vietnam: Causes and Options for Control. *Agric. Water Manag.* **2010**, *97* (6), 872–882. https://doi.org/10.1016/j.agwat.2010.01.018.
28. Casillas-Hernández, R.; Nolasco-Soria, H.; García-Galano, T.; Carrillo-Farnes, O.; Páez-Osuna, F. Water Quality, Chemical Fluxes and Production in Semi-Intensive Pacific White Shrimp (Litopenaeus Vannamei) Culture Ponds Utilizing Two Different Feeding Strategies. *Aquac. Eng.* **2007**, *36* (2), 105–114. https://doi.org/10.1016/j.aquaeng.2006.09.001.
29. McIntosh, D.; Samocha, T. M.; Jones, E. R.; Lawrence, A. L.; Horowitz, S.; Horowitz, A. Effects of Two Commercially Available Low-Protein Diets (21% and 31%) on Water and Sediment Quality, and on the Production of Litopenaeus Vannamei in an Outdoor Tank System with Limited Water Discharge. *Aquac. Eng.* **2001**, *25* (2), 69–82. https://doi.org/10.1016/S0144-8609(01)00073-5.
30. Montoya, R. A.; Lawrence, A. L.; Grant, W. E.; Velaso, M. Simulation of Nitrogen Dynamics and Shrimp Growth in an Intensive Shrimp Culture System: Effects of Feed and Feeding Parameters. *Ecol. Modell.* **1999**, *122* (1–2), 81–95. https://doi.org/10.1016/S0304-3800(99)00123-4.
31. Boyd, C.; Green, B. *Coastal Water Quality Monitoring in Shrimp Farming Areas: An Example from Honduras*; 2002.
32. Rajasegar, M. Physico-Chemical Characteristics of the Vellar Estuary in Relation to Shrimp Farming. *J. Environ. Biol.* **2003**, *24* (1), 95–101.
33. Wu, R. S. S.; Lam, K. S.; MacKay, D. W.; Lau, T. C.; Yam, V. Impact of Marine Fish Farming on Water Quality and Bottom Sediment: A Case Study in the Sub-Tropical Environment. *Mar. Environ. Res.* **1994**, *38* (2), 115–145. https://doi.org/https://doi.org/10.1016/0141-1136(94)90004-3.