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Full length Research paper

Mixed culture (shrimps, oysters and macroalgae) to improve the productivity, and reduce the environmental impact to coastal ecosystem caused by shrimp hatcheries in Mexico

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In Mexico, shrimp hatcheries have been developed as intensive monocultures, resulting in hatcheries management troubles, economic losses and environmental impact. Therefore, the aim of this work was compare to a traditional culture vs. a mixed culture. Shrimp juveniles were distributed in aquariums and ponds at the same density (51 shrimps/m^2) but ponds, also had oysters and macroalgae. Shrimps in aquaria and ponds were feed with same food amount. Water was change each two days, but in ponds only 20%. To compare traditional vs. mixed culture, shrimp's growth, feed efficiency conversion and nutrients concentration, in aquariums and ponds were recorded. At experiment's end, shrimps grew 35% more in ponds than aquariums; feed efficiency conversion was 0.68 units lower in ponds than aquariums, and NH_4 concentrations were close to 3 and 1 mg/L in aquariums and ponds respectively. The mean increase weight in oyster and macroalgae, was 4.04 and 19.3 g respectively. Therefore, mixed culture has many ecological and economic advantages over traditional culture. Therefore it is suggested that scaling this technology to commercial level, in addition to shrimps, oysters and macroalgae are produced, which could be used for human consumption and animal fodder respectively. Also, this model improves water quality and reduces the environmental impact.

Key words: Shrimp-monoculture, mixed-culture, oysters, macroalgae, higher productivity, water quality, environmental impact.

INTRODUCTION

In many countries, the aquaculture activities have grown vertiginously during the last decades. The shrimp cultivation in ponds under controlled conditions is one of most important of these activities (FAO, 2008); however, this biotechnology has been developed with many failures, because it is based on not ecological principles, such as intensive monoculture which have resulting with many troubles in the hatcheries management, economic losses and also an increasing environmental impact due to deforestation of mangroves and salt marshes, and excess of organic matter, nutrients and pollutants drained to coastal ecosystems, where the hatcheries are located (Primavera, 1998; Trott and Alongi, 2000).

The shrimp world production is not available because there are no data of many producer countries; however, the shrimp importation by the principal regions or

Table 1. Principal importers of shrimp in the world. The product is frozen (with or without head).

Year	2006	2007	2008	2009	2010	2011
Total (M. Ton)	727945	732022	700960	693667	697139	738878
Japan	115000	116000	105000	102000	115000	110000
E. Union	370000	370000	310000	370000	380000	390000
USA	242945	246022	285960	221667	202139	238878

(Source: www.goblefish.org/shrimp-december-2011.html).

Figure 1. Typical shrimp hatcheries in the NW coast of Mexico (Source: Google.ca/imgres q=shrimp+hatcheries+in+Mexico).

countries in the world, is shown in Table 1, which give an idea of shrimp's world production during 2011. Mexico held the sixth place in the world as shrimp producer after China, India, Ecuador, Thailand and others Asiatic countries (CONAPESCA, 2011).

As currency income, the shrimp fishery is the most important in the country; this yielded $10860 millions of Mexican pesos in 2009; approximately $868.8 millions of USD (INEGI, 2009). This fishery grew around 13000 Metric Ton per year from 2003 to 2011 (CONAPESCA, 2011). In 2009, the production reached 181000 Metric Ton. The same source, report that for each Metric Ton, 671 Kg are produced in hatcheries and 329 Kg are fishing in estuaries, coastal lagoons and adjacent sea; therefore, 67.1% of production corresponds to aquaculture. However, all the hatcheries are located in the coastal ecosystems, i.e estuaries, salt marshes and coastal lagoons (Figure 1).

In NW of Mexico, Sonora and Sinaloa are the States (provinces), which produce 71.6% of shrimp in the county (Figure 2). The shrimp aquaculture has been expanding rapidly in these States, but due to "successful", shrimp hatcheries also are settling in the Baja California peninsula (DeWalt et al., 2002).

The number of producers nearly doubled in the period between 1993 and 2010 to nearly 600 farms; there are now nearly 20,000 ha of shrimp aquaculture ponds in the region; and the average yields are approximately 1.34 Tons per hectare (CONAPESCA, 2011). However, only 460 to 480 are in operation; the others are closed due to diverse troubles (Dr. Audelo Naranjo, Facultad de Ciencias del Mar, Universidad Autonoma de Sinaloa, personal communication). Such as has seen in other countries, the shrimp aquaculture in Mexico has far developed largely with some detrimental environmental effects (McKinnon et al., 2002). Considerable evidence of mangrove destruction has been reported. There are no official data, but some authors have reported that mangroves and salt marshes in the Sinaloa coast are disappearing at rate of 2 to 3% annually (Martínez–Córdova et al., 1998; Boyd and Gautier, 2000; Páez-Osuna, 2001).

But the most serious potential threat from shrimp aquaculture in Mexico, is the impacts at water quality (DeWalt et al., 2002). Some authors have reported that detrimental water quality drained into coastal ecosystems is due to high amount of organic matter, high nutrient concentration (particularly NH_4, by their toxicity), increased level of coliform bacteria, organic pollutants such as antibiotics, pesticides and in some cases heavy metals (Páez-Osuna et al., 1999; Trott and Alongi, 2000; Galindo et al., 2008; Martínez-Córdova et al., 2009). Many of these compounds comes from excess of supplied food for fast grow shrimp, which is required by

Figure 2. States of Mexico where are located the major number of shrimp hatcheries in the country (adapted from Google Earth, satellite image).

high density of shrimps per square meter in the ponds (30-55 in intensive hatcheries; 80-200 in super intensive hatcheries), excess use of antibiotics, and biocides to combat shrimp diseases, pollution by diesel and oil used for water pumps and blowers, abandoned batteries, etc. (Boyd and Gautier, 2000; DeWalt et al., 2002).

Faced with this problem, the objective of this work is the implementation of mixed cultures, which in addition to shrimp, contemplates use of filter feeders such as oysters (Crassostrea spp.) and cultivation of macro-algae (Ulva spp.) known as "sea lettuce" in the effluent of shrimp ponds, or in the same pond. This could reduce particulate organic matter, bacterial load, nutrients excess and some biocides. In other words, this shrimp's productive model, will seems closer to coastal ecosystem, where energy and material fluxes, are not altered excessively; therefore, the ecosystem keeps his homeostasis, reducing environmental impact and increasing the shrimp productivity.

MATERIALS AND METHODS

Certificated shrimp larvae (*Litopenaeus vannamei*) were obtained from a commercial larvae producer. The larvae were maintained in an aquarium (18-21°C, 28 psu salinity, 5.5-7.1 ml/L dissolved O_2). As food, brine eggs were supplied four times per day during one month, until the larvae reached the juvenile stage (mean weight 0.72 g, mean size 49 mm) then, shrimp juveniles were transferred to three aquariums (0.43 m^2, 68 L) 66 juveniles per aquarium. The aquariums water was changed each two days, aeration was permanent and physical-chemical parameter (pH, salinity, dissolved oxygen, temperature, and total suspended solids) were recorded, using a Hanna® multiparameter apparatus, Model HI 9828. The nutrients concentrations were quantified following the protocols presented by (Strickland and Parsons, 1972).

Brand food (camaronina) Purina ® was supplied two times per day at rate of 12% total biomass (11-12 g/day). In order to keep the aquaria at similar conditions, the shrimp number per aquaria was maintained equal; so dead shrimps were replaced immediately. At the same time, oysters Crassostrea corteziensis (mean weight 8.2 g, mean size 37.5 mm) and macro-algae Ulva spp. (68 g) were put into three plastic ponds (0.78 m^2, 240 L); the oyster's number per pond was 46. The source and conditions of water in ponds were same as in aquaria, but no food was supplied, because no shrimps there were. Also water was changed each two days, but only 20% total volume (48 l/pond). The same physical–chemical parameters were recorded, and dead oysters were replaced.

When shrimps reached 1.9 g (mean weight) and 61 mm (mean size), they were redistributed into aquariums and ponds (three each), 22 shrimp per aquarium and 40 per pond; therefore, shrimp density was same in each (51 shrimps/m^2). In order to compare traditional shrimp culture (aquariums) vs. mixed culture (ponds), the growth rate, the feed efficiency conversion and the nutrients concentration in water, both in aquariums as in ponds were recorded. During this experimentation time, same routine works were performed; that is, water change each 2 days, record of physical-chemical parameters, etc. Also, due to shrimp's growth, the supply of food in aquariums and ponds was increased to 13 to 13.5 g/day; and the amount of macroalgae was increased to 159 g per pond. Shrimp mortality was recorded each day, and three weeks after, the experiment was finished.

Statistical analysis

All physical-chemical parameters, chemical analyses and growth parameters were realized by triplicate. A statistical program MYSTAD® was used to obtain the mean and standard deviation for each variables group and an ANOVA with the Shapiro-Wilk test for normality and Fisher test for homoscedasticity, to calculate the significance values (p).

RESULTS

During first part of this work (January 8 to February 18), there were no relevant changes; just a "normal" growth of shrimps in aquariums. The increase mean weight was 0.63 g (from 0.09 to 0.72), with a standard deviation (S.D.) of 0.05, and in length 43 mm (from 4-7 to 49 mm), with a S.D. of 2.5. The mean growth of oysters in ponds was 1.87 g (from 8.2 to 10.07), with a S.D. of 1.15, and in length 3.9 mm (from 37.5 to 41.4) with a S.D. of 3.1 during the same period. The physical-chemical parameters in ponds and aquariums do not presented relevant differences, except dissolved oxygen and pH, which were significant lower in aquaria than in ponds (Table 2). The p-values ranged from 0.000 to 0.024 for dissolved oxygen, and from 0.002 to 0.031 for pH.

The values of physical-chemical parameters during the second part of experiment (March 5 to March 28) are summarized in Table 3. No significant differences between aquariums and ponds were observed for physical-chemical parameters, except for pH and dissolved oxygen, which were significant higher in ponds than aquariums (p-values ranged from 0.000 to 0.029 for dissolved oxygen, and from 0.007 to 0.035 for pH). The total suspended particles (TSS) were moderately higher

Table 2. Physical–chemical parameters during first part of experiment (January 8 to February 18). The ponds had only oyster and macroalgaea; the aquaria just shrimps.

Data	Aquarium or pond	Salinity (psu)	Dis O_2 (ml/l)	Temp (°C)	pH	TSS(ppb)
Jan./8/2012	Pond 1	28	7.4	19	7.7	19500
Jan./8/2012	Pond 2	28	7.2	19	7.5	18987
Jan./8/2012	Pond 3	28	7.3	19	7.7	19500
Jan./8/2012	Aquarium 1	28	4.2	19	7.3	17510
Jan./8/2012	Aquarium 2	28	3.9	19	7.3	17680
Jan./8/2012	Aquarium 3	28	5.4	19	7.4	17670
Feb./8/2012	Pond 1	28	7.6	21	7.8	18763
Feb./8/2012	Pond 2	28	7.5	21	7.7	19001
Feb./8/2012	Pond 3	28	7.4	21	7.8	18720
Feb./8/2012	Aquarium 1	28	3.2	21	7.2	18010
Feb./8/2012	Aquarium 2	28	3.2	21	7.2	18000
Feb./8/2012	Aquarium 3	28	3.1	21	7.1	18480
Feb./18/2012	Pond 1	28	7.4	19	7.7	19206
Feb./18/2012	Pond 2	28	7.4	19	7.5	19259
Feb./18/2012	Pond 3	28	7.5	19	7.5	18760
Feb./18/2012	Aquarium 1	28	4.7	19	7.3	17530
Feb./18/2012	Aquarium 2	28	4.7	19	7.3	17880
Feb./18/2012	Aquarium 3	28	5.1	19	7.4	18000

Table 3. Physical-chemical parameters during second part of experiment (March 5 to March 28). The ponds had oyster, macroalgae and shrimps; the aquaria just shrimps.

Data	Aquarium or pond	Salinity (psu)	Dissolved O_2 (ml/l)	Temp (°C)	pH	TSS (ppb)
March/5/2012	Pond 1	28	7.1	20	7.8	22897
March/5/2012	Pond 2	28	7	20	7.5	23065
March/5/2012	Pond 3	28	7.2	20	7.6	23110
March/5/2012	Aquarium 1	28	4.9	20	7.4	17550
March/5/2012	Aquarium 2	28	4.3	20	7.4	21100
March/5/2012	Aquarium 3	28	4.1	20	7.5	19970
March/12/2012	Pond 1	29	6.9	21	7.7	22659
March/12/2012	Pond 2	29	6.2	21	7.5	22920
March/12/2012	Pond 3	29	6.5	21	7.4	19760
March/12/2012	Aquarium 1	29	4.9	21	7.2	19310
March/12/2012	Aquarium 2	29	4.3	21	7.2	19500
March/12/2012	Aquarium 3	29	4.3	21	7.2	18720
March/18/2012	Pond 1	28	6.8	21	7.7	22789
March/18/2012	Pond 2	28	6.9	21	7.8	23100
March/18/2012	Pond 3	28	6.9	21	7.5	22986
March/18/2012	Aquarium 1	28	4.9	21	7.2	21970
March/18/2012	Aquarium 2	28	4.6	21	7.2	21900
March/18/2012	Aquarium 3	28	4.5	21	7.3	21890
March/24/2012	Pond 1	28	6.4	20	7.6	22765
March/24/2012	Pond 2	28	6.5	20	7.6	22500
March/24/2012	Pond 3	28	6.4	20	7.5	21900
March/24/2012	Aquarium 1	28	4.5	20	7.3	19500
March/24/2012	Aquarium 2	28	4.4	20	7.2	21400
March/24/2012	Aquarium 3	28	4.1	20	7.2	18740
March/28/2012	Pond 1	28	6.4	20	7.7	22234
March/28/2012	Pond 2	28	6.2	20	7.8	22750

Table 3. Contd.

March/28/2012	Pond 3	28	6.3	20	7.5	21010
March/28/2012	Aquarium 1	28	5.7	20	7.3	19120
March/28/2012	Aquarium 2	28	5.5	20	7.2	19210
March/28/2012	Aquarium 3	28	5.1	20	7.3	20600

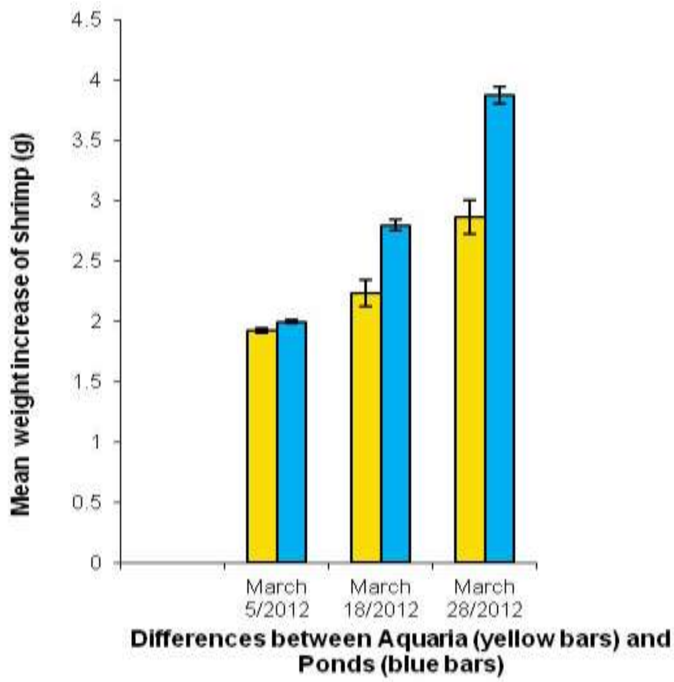

Figure 3. Differences in weight Increase of shrimp (mean values) between traditional culture and mixed culture (p-values were 0.041, 0.001 and 0.000 for March 5, 18 and 28 respectively).

in ponds than in aquariums; however, the significance values (p) were of 0.057, 0.005 and 0.029 for March 5, 18 and 28 respectively. However, during second part of experiment important differences were registered between traditional cultures (aquaria) vs. mixed culture (ponds), which becomes the relevant points of this work.

Figure 3 shows the differences in mean weight increase of shrimps between mixed culture and the traditional one. As can be observed, the values were significant higher in ponds than in aquariums, even though food supplied was the same in both cultures, and the shrimp number per aquarium was 22, whereas in ponds 40 in each one. Therefore, at the end of experiment, with same amount of food, the shrimps gained 35% more weight in ponds than in aquariums [(3.87g W. in ponds/2.86 g W. in aquariums) ×100-100]; which means an economy of 35% in food supplied.

Also the feed conversion factor, which is relationship between the amount of food supplied divided by the biomass increase of shrimp, was significantly lower in the mixed culture than in traditional one (Figure 4). At the end of experiment, this difference was 0.68 units or 44.7% lower in ponds than aquariums. This means that shrimps have higher metabolic efficiency in pond than in aquariums, or have others food sources, or both; which also becomes an economy of food supplied. In fact, as it was indicated above, the TSS were moderately higher in ponds than in aquariums during second part of experiment. As can be observed in Table 3, the TSS in ponds, ranged from 19760 to 23110, whereas in aquariums, the values ranged from 17550 to 21970; this means a moderately higher organic matter amount in ponds than in aquariums, particularly at the end of experiment.

Regarding oysters and macroalgae; at the end of experiment, oyster mortality was 14%, leaving about 39 oysters per pond. The final mean size of oysters was 47.1 mm, with a S.D. of 3.59, and the mean weight 14.11 g with a S.D. of 1.35. Therefore in a period of 37 days (from February 20 to March 28) the mean increase weight was 4.04 g (from 10.07 to 14.11) and the increase of size 5.7 mm (from 41.4 to 47.1). The algae biomass also had a mean increase weigh of 19.3 g (from 159 to 178.3) per pond with a S.D. of 4.25, during same period. Concerning to nutrient concentrations; the ammonia was the nitrogen compound which registered significant differences between aquariums and ponds (Figure 5). As observe, at all times ammonia concentrations were significant higher in the aquariums than in ponds. The ammonia in ponds was almost unchanged, also the differences were greater toward end of experiment when the macroalgae biomass was higher in ponds. The nitrate concentrations in water are shown in Figure 6. Contrary to ammonia values, the differences of nitrate concentration between aquariums and ponds were not significant, however, as the experiment progressed, the nitrates increased both in aquariums as in ponds.

The phosphate concentration in aquariums and ponds are shown in the Figure 7. As can be observed there are not significant differences between aquariums and ponds, except at March 5. However, the phosphates increased moderately in ponds as experiment progressed, whereas in aquariums were almost unchanged. The N/P relationship found in this work ranged from 4.15 to 17.45 in aquariums and from 8.7 to 13.96 in ponds.

DISCUSSION

From the results obtained, it is possible to reach the

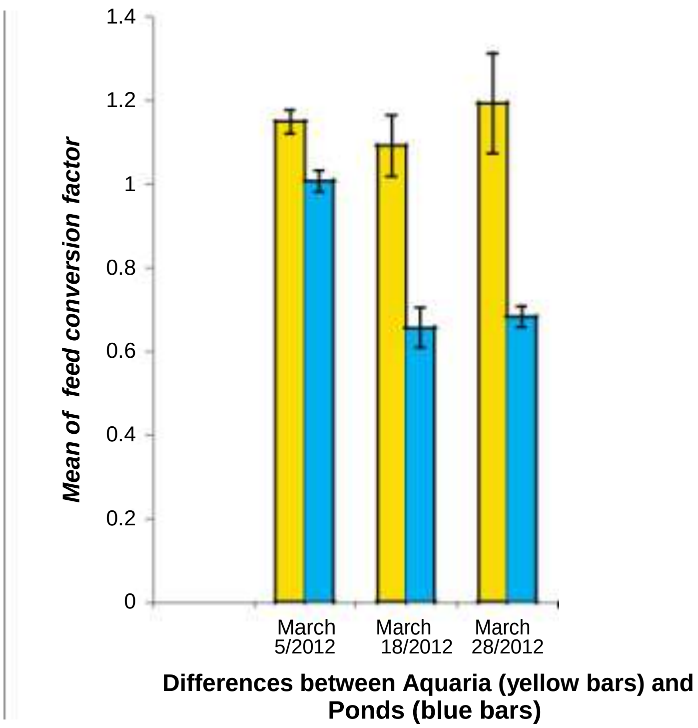

Figure 4. Differences in feed conversion factor (mean values) between traditional culture and mixed culture (p-values were 0.037, 0.014 and 0.008 for March 5, 18 and 28 respectively).

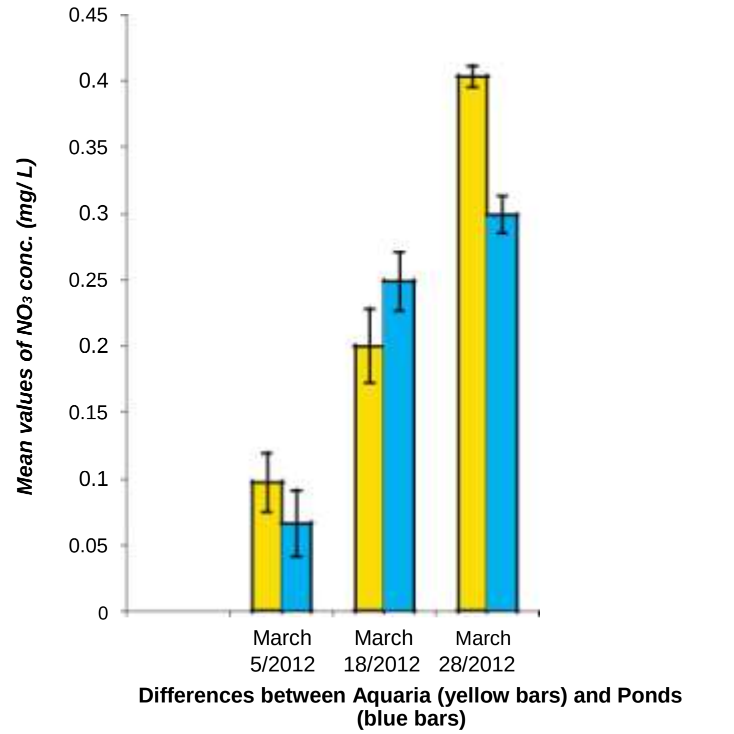

Figure 6. Differences in nitrate concentrations (mean values) between aquariums and ponds, during the second part of experiment ($p \geq 0.076$), except at March 28 ($p=0.000$).

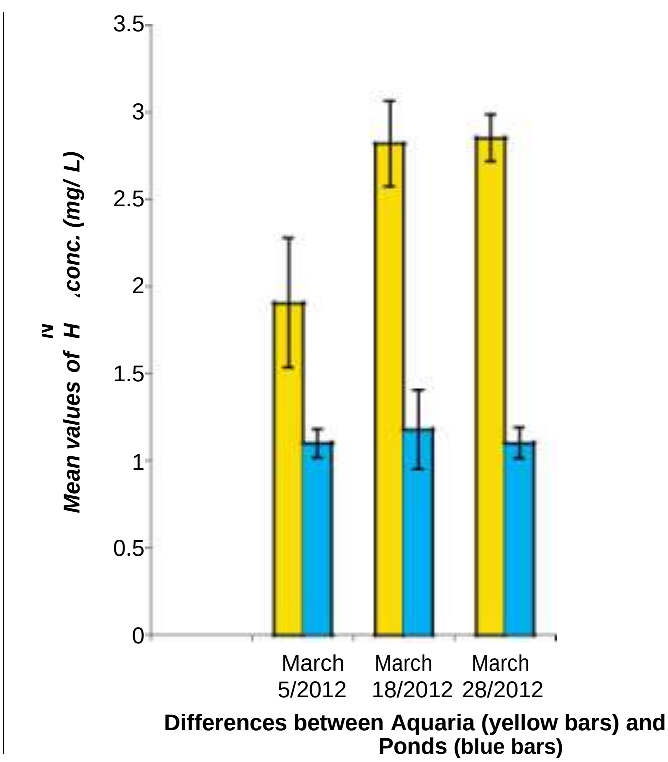

Figure 5. Differences in ammonia concentrations (mean values) between aquariums and ponds, during the second part of experiment (p-values were 0.023, 0.005 and 0.000 for March 5, 18 and 28 respectively).

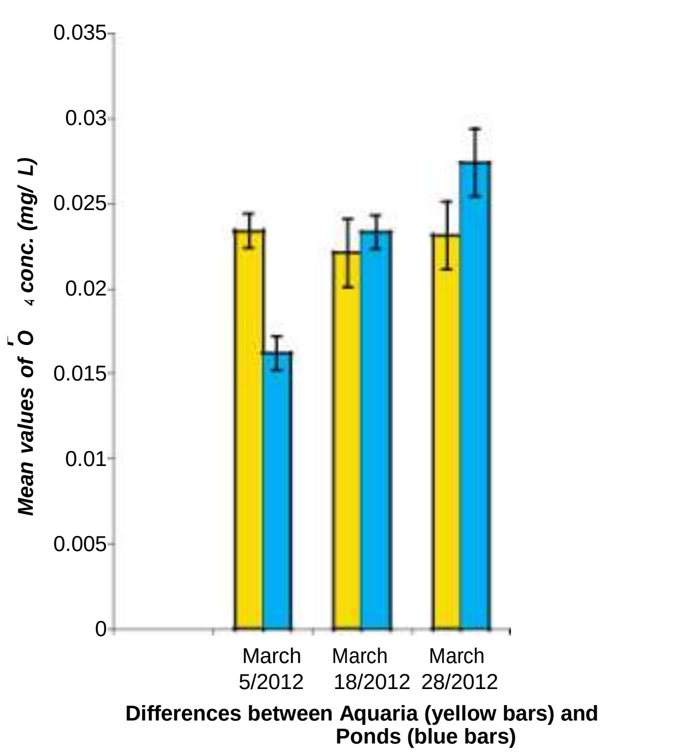

Figure 7. Differences in phosphate concentrations (mean values) between aquariums and ponds, during the second part of experiment. ($p \geq 0.062$), except at March 5 ($p=0.000$).

following conclusions and relevant points about the advantages of mixed culture (ponds) over traditional one (aquariums).

1. The growth rate of shrimps was higher in the mixed culture than in the traditional one (Figure 3) because the shrimps reached a higher weight in ponds than in aquariums during the same period of time, and with the same amount of food supplied. This means that shrimps in the ponds must have others sources of food, such as phytoplankton and detritus which are not available or are not in the same amounts in the aquariums. This becomes an important issue, because in the commercial shrimp hatcheries, the reduction in the growth time is an important thing, because the production costs becomes reduced as the growth period also is reduced. Others authors claims similar conclusions (Martínez-Córdova et al., 1997).

2. The feed conversion factor also is higher in the mixed culture than in the traditional one (Figure 4). This indicates that the efficiency of food assimilation (metabolic efficiency) is higher in ponds than in aquariums, which means an economy of food supplied; therefore in money in the commercial hatcheries, because in the mixed culture the food supplied was 35% less than in the traditional one.

3. The total amount of water changed, was 30% less in ponds than in aquariums; because in the ponds, was 144 L (48 L/pond) each two days, whereas in aquariums was 204 L(68 L/ aquarium) in the same time period. This means an economy in water consumption, which is a very important point because in commercial shrimp hatcheries, the water is pumped from the sea or estuaries toward the ponds; therefore, the energy consumption (electricity or diesel) will be 30% less in the mixed culture than in the traditional one.

4. Concerning to ammonium concentrations in water, the values registered in this work, were into the "normal" ranges. Other authors report similar concentrations in ponds of shrimp hatcheries (Arencibia, 1996; Páez-Osuna et al., 1999, 2001; Pis et al., 2010; Pereira et al., 2011). Common values in semi-intensive shrimp hatcheries, are from 0.1 to 2 mg/L, and in the intensive cultures, values are close to 4 (Boyd and Tucker, 1998) however, the same authors claims that when ammonia concentration increase, it can create problems in the shrimps, such as low growth and more susceptibility to diseases. In this work the ammonia concentration reached concentrations close to 3 mg/L in aquariums, whereas in the ponds, maximum values were around 1 mg/L (Figure 5). This could be attributed to macroalgae, which are consuming this nutrient for growth; therefore, the elevated ammonia concentration recorded in the aquariums, which is a deleterious factor for the shrimp, is not a problem in ponds, consequently, the mixed culture is much more successful that traditional one. Although there were not significant differences in nitrate concentrations between aquariums and ponds during the experiment, the nitrate values are slightly higher compared to those reported by Pis et al. (2010) and Pereira et al. (2011). This could be due to several factors; one of these, are the intense nitrification processes, because at high O_2 concentration and pH values greater 7.5, which were recorded in ponds (Table 3), the Nitrosomas bacteria reduce NH_4 to nitrites, and then, nitrites are oxidized to nitrates by Nitrobacteria (Boyd and Tucker, 1998). Other important factor is the production/consumption relationship, which is higher in the first part of experiment than in the second one, because in the second one, the consumers are more (phytoplankton, macroalgae, etc.). During the second part of experiment, the biomass of macroalgae was increased from 159 to 178.3 g.

Conclusions

The phosphorous concentrations found in this work, are within normal ranges. Other authors report similar phosphorus concentrations in commercial shrimp hatcheries (Jackson et al., 2003; Lacerda et al., 2006). Also, the N/P relationship found, are within ranges reported by Jones et al. (2001) and Alonso-Rodriguez and Páez-Osuna, 2003) however, the N/P relationship in ponds (mixed culture), are closer to 15, which correspond to coastal waters less disturbed. This suggest that metabolism and recycling of nutrients by bacteria are more efficient in mixed culture than in traditional culture, because the nutrients in shrimp hatcheries comes from food supplied and recycling (Briggs and Funge–Smith, 1994; Páez-Osuna et al., 1997).

From the above comments, we can conclude that mixed culture has many advantages over the traditional one; not only on the production efficiency and economy aspects, but also on the improvement in water quality. On the other hand, with the same amounts of water and food, we obtained a good growth of oysters and macroalgae. This represents a plus in the productivity, because the oysters can be edible after a simple treatment to clean up them; and the macroalgae can be used as animal fodder. Other authors propose to use macroalgae, to reduce the eutrophication in effluents of shrimp culture (Primavera, 1998; McKinnon et al., 2002).

Finally, we could demonstrate, at laboratory level, that mixed culture of shrimp (ponds) has many ecological and economic advantages over the traditional culture (aquariums). So, we suggest scaling this technological model of shrimp production to commercial level, in order to replace the obsolete traditional model, improve the water quality, and reduce environmental impact on coastal ecosystems.

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