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Environmental Load of Nitrogen and Phosphorus from Extensive, Semiintensive, and Intensive Shrimp Farms in the Gulf of California Ecoregion

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It is estimated that one million ha of coastal lowlands have been converted into shrimp farms, mainly in China, Thailand, India, Indonesia, Philippines, Malaysia, Ecuador, Mexico, Honduras, Colombia, Panama and Nicaragua (FAO 1999). Mexico has a total area dedicated to shrimp farming of 52,648 ha, of which 51,059 ha (97%) are located around the Gulf of California and until 2001, there are 190 ha in Baja California; 128 ha in Baja California Sur; 9,951 ha in Sonora; 37,390 ha in Sinaloa; and 3400 ha in Nayarit (SAGARPA /CONAPESCA 2002). There are several potential deleterious effects from shrimp pond effluents on the water quality of the estuarine/ lagoon environments which include oxygen depletion, light reduction, hypernutrification and eutrophication. However, such effects depending on the management and technology applied, the scale of the production, and the capacity of the receiving waters (Páez-Osuna 2001a). The purpose of the present study was to examine and evaluate the environment load of nutrients, both nitrogen and P, from the three shrimp culture systems practiced in the Gulf of California ecoregion, extensive, semi-intensive and intensive. Additionally, is discussed the global discharge of N and P in terms of population equivalent.

MATERIALS AND METHODS

The more common management system in the ecoregion of the Gulf of California is the semi-intensive type (89%), while intensive and extensive types comprise only 2 and 9%, respectively. The mean stock density for intensive shrimp farms is 58 postlarvae per m^2 (PL/m^2), for the semi-intensive 13 PL/m^2, and for extensive 7 PL/m^2; 39% of the farms stock blue shrimp (*Litopenaeus stylirostris*), 37% stock white shrimp (*L. vannamei*) and 24% stock both species. More details on the management and characteristics of shrimp ponds are summarized and described in Páez-Osuna (2001b) and Páez-Osuna et al. (2003).

The global load of nutrients derived from the shrimp aquaculture can be estimated from two strategies: one, using a representing model for most farms in the region (Páez-Osuna et al. 1999), and other, using an individual model for each type of management system, and next simply multiplying by

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the area (ha) dedicated to aquaculture in the ecoregion. In the second case the model considered the following conditions: (1) although the period of the culture cycle was assumed to have a duration of 120 days in the three culture systems, extensive, semi-intensive and intensive, can be really variable depending of the market demand and the presence or threat of diseases; (2) even when the daily water exchange can varies from 3 to16%, most of the farms have a mean exchange rate of 4%; (3) the composition of the food used in the three type of farmers is variable, but most of the times the three culture systems use a 35% of protein and 1.2% of phosphorus; (4) the food coefficient (dry wet food added/wet weight of shrimp produced) varies depending of season and management, ranging from 1.0 to 2.6, but most frequently is between 1.1 and 1.8; here a feed coefficient of 1.5 was assumed for each culture system; (5) the fertilization in the semi-intensive and intensive shrimp ponds was of 6.8 kg/ha of triple superphosphate (46% P_2O_5) and 29.5 kg/ha of urea (45% N), while in the extensive ponds were not fertilized (Páez-Osuna 2001b); (6) the N and P contents in shrimp is of 0.37% P and 3.41% N in wet weight, i.e., 1.2% P and 11.0% N in dry weight (Boyd and Teichert-Coddington 1995; Páez-Osuna et al. 1997); (7) the concentration of N and P in the water introduced from estuarine and lagoon environments were of 346-378 N ug/L and 124-161 P ug/L. These ranges were obtained in a study on the water quality of four commercial aquaculture facilities located in the center-southern region of Sinaloa state (Páez-Osuna et al. 1999; Ruiz-Fernández and Páez-Osuna 2004); (8) the concentration of N and P in the output water is variable, however, in a previous assessment of four shrimp farms in the region (Páez-Osuna et al. 1999; Ruiz-Fernández and Páez-Osuna 2004), it was observed that the intensive ponds had a average of 172 ug N/L and 206 ug P/L, while in semi-intensive ponds was 197 ug N/L and 180 ug P/L, the effluents of extensive ponds were assumed to be similar or identical in composition that semi-intensive ponds due most extensive farms apply food as semi-intensive, and; (9) the harvest or production was taken from the regional average for extensive, semi-intensive and intensive ponds, i.e., 300, 900 and 2000 kg/ha, respectively.

Considering the gross nutrient mass balance, the environmental losses of P (Lp) or N (Ln) is given by the next equation (Páez-Osuna et al. 1999):

$$L_p = F\,C_{Fp} + f\,C_{fp} + I\,C_{Ip} - H\,C_{Hp} \quad (1)$$

$$L_n = F\,C_{Fn} + f\,C_{fn} + I\,C_{In} - H\,C_{Hn} \quad (2)$$

Where $\mathbf{C_F}$, $\mathbf{C_f}$, $\mathbf{C_I}$ and $\mathbf{C_H}$ refer to the content of N and P in the food dry pellets (F), the fertilizer (f), the input water (I), and the shrimp harvest (H), respectively. L is reduced with the increment of harvest or/and the reduction of food, fertilization and input water rates. It is important indicate that the environmental losses L includes the load of nutrients discharged via output water, denitrification and volatilization to the atmosphere and sedimentation to the pond bottom, which eventually, could be removed at the end of the culture cycle. Some farms treat the pond sediments and remove them every determined number of crops.

RESULTS AND DISCUSSION

Using the strategy proposed by Tucker and Boyd (1985) a first mass balance for the fate of nutrients in the food added to shrimp ponds was developed based on estimates of feed conversion, the amount of food added, the dry weight concentration of N and P and the moisture content of food and shrimp. Clearly, the mass balance presented on Table 1 reveals differences in the efficiencies on the utilization of the shrimp food in each culture system and the lost of nutrients that are incorporated to the water pond. The amount of unconsumed food depends of the management, the species involved, the environmental conditions, and the type of food. In the case of extensive and semi-intensive systems 40.5% of nitrogen added with food is recovered as biomass of the harvest, and consequently 59.5% is liberated to the pond water, and 20.4% of phosphorus is recovered and the rest released to the water. The remaining nitrogen and phosphorus is liberated to the water column as decomposition or excretory products and eventually incorporated in the natural cycles of the ponds. Nitrogen is liberated through the output water, sediments and by volatilization and denitrification to the atmposhere (Páez-Osuna et al. 1997), while phosphorus is liberated from the ponds via the output water and the sediments. It is clear, that for both nutrients the absolute amounts and percentages of recovering of harvest in the intensive ponds are more elevated than in the other systems.

Considering the assumptions and the general conditions of the Gulf of California ecoregion, three gross mass balances for nitrogen and phosphorus were elaborated for the three management systems practiced (Fig. 1 and 2). For extensive ponds, of the total nitrogen and phosphorus input, 24% and 9% were recovered in the 300 kg of shrimp harvested per ha per cycle. Denitrification and volatilization of ammonium, and adsorption by sediments of nitrogen and phosphorus constituted 55% and 28%, respectively. For semi-intensive ponds, of the total nitrogen and phosphorus input, 29% and 14% were recovered in the 900 kg of shrimp biomass harvested per ha per cycle; and losses due to denitrification and volatilization of ammonium and uptake by sediments of nitrogen and phosphorus constituted 63% and 55%, respectively. For intensive ponds, of the total nitrogen and phosphorus input, 52% and 25% were recovered in the 2000 kg of shrimp biomass harvested per ha per cycle; while losses to the environment accounted for 44% and 55%, respectively.

From equations (1) and (2) nutrient loads per ha cultured per cycle at each system were: for nitrogen, 31.3 kg/ha, 74.6 kg/ha and 95.4 kg/ha for the extensive, semi-intensive and intensive ponds, respectively; for phosphorus, 10.9 kg/ha cycle, 19.9 kg/ha cycle and 33.0 kg/ha cycle for extensive, semi-intensive and intensive ponds, respectively. These figures

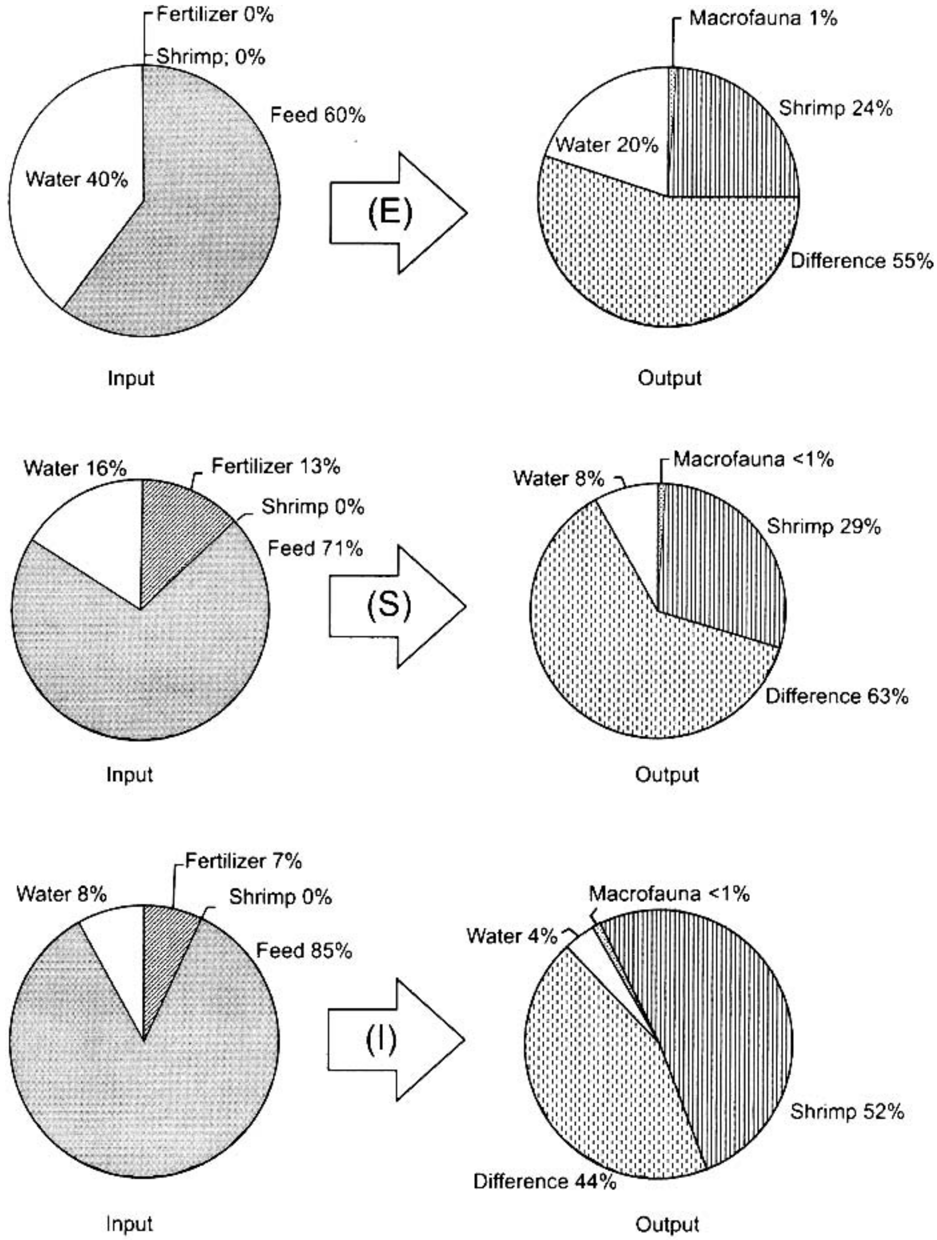

Figure 1. Nitrogen mass balance for extensive (E), semi-intensive (S) and intensive (I) shrimp ponds.

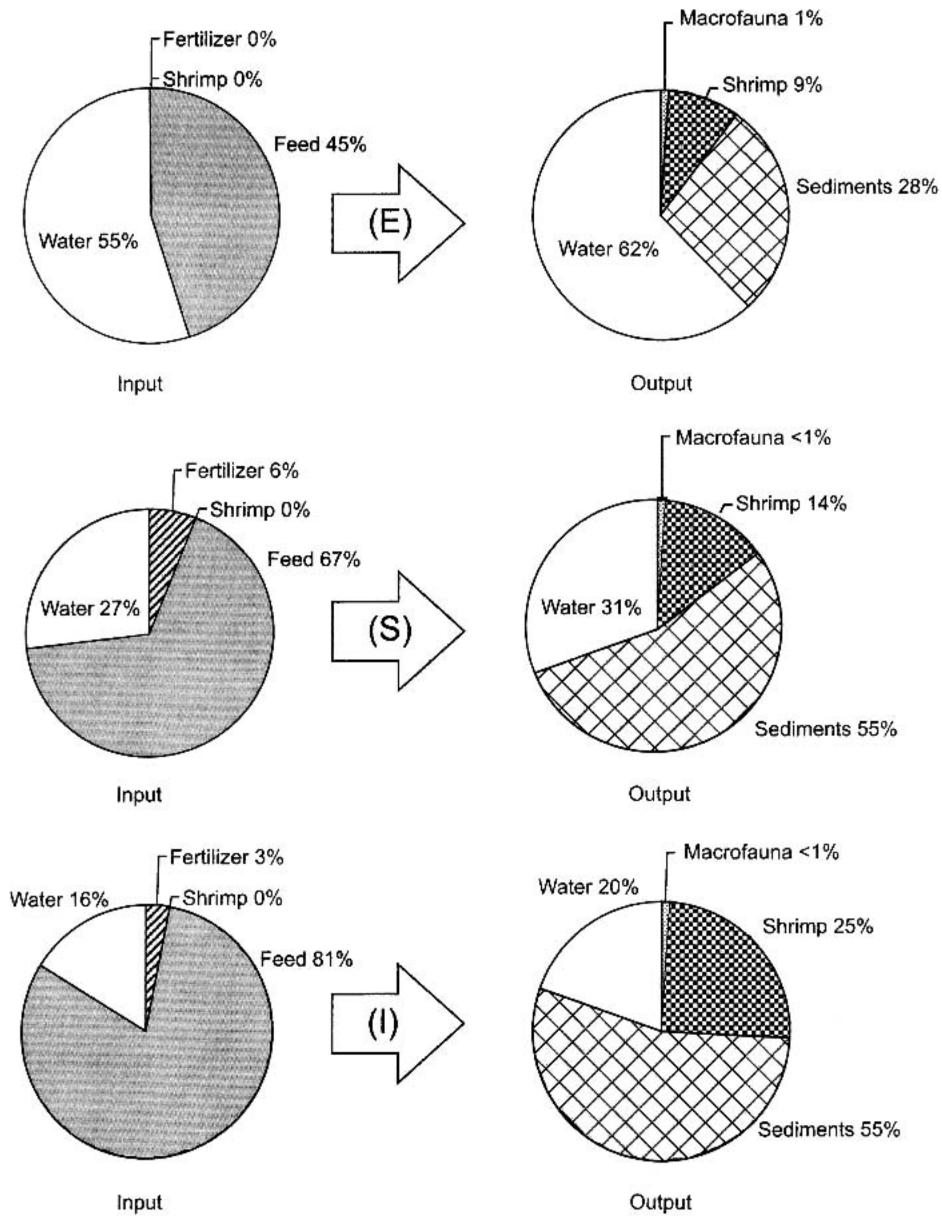

Figure 2. Phosphorus mass balance for extensive (E), semi-intensive (S) and intensive (I) shrimp ponds.

Table 1. Balance for nitrogen and phosphorus derived from the food in a extensive, semi-intensive and intensive pond, when the harvest is of 300, 900 and 2000 kg/ha with a feed conversion ratio of 1.5 and on one ha.

	Added in feed (kg/ha)	Removed in shrimp (harvest) Kg (% in feed)	Lost to water (kg/ha)
Extensive ponds			
N	25.2	10.2 (40.5%)	15.0
P	5.4	1.1 (20.4%)	4.3
Semi-intensive ponds			
N	75.6	30.6 (40.5%)	45.0
P	16.2	3.3 (20.4%)	12.9
Intensive ponds			
N	168.0	102.3 (60.9%)	65.7
P	36.0	1.1 (30.8%)	24.9

clearly evidence that intensive ponds have a major impact in terms of nutrients discharged to the environment, than extensive and semi-intensive shrimp ponds; however, when the load is examined in terms of biomass of shrimp produced, the contrary tendency is observed: for nitrogen, 104 kg/ton, 83 kg/ton and 48 kg/ton for the extensive, semi-intensive and intensive ponds, respectively, and for phosphorus, 36 kg/ton, 22 kg/ton and 17 kg/ton for extensive, semi-intensive and intensive ponds, respectively. In conclusion one ton of shrimp produced in extensive farms represents a higher nutrient load for the environment than being produced in intensive farms. It is important to indicate that due to intensive farms discharge their water effluents in restricted areas (i.e., higher nutrient load by receptacle area), these could represent a higher impact than produced by semi-intensive and extensive systems, where effluents are discharged in wider open areas. However, the magnitude of the impacts involved in each case is still to be evaluated.

When are examined the nutrient loads per ha cultivated and per ton of shrimp produced from different areas of the world and culture systems (e.g., Martin et al. 1998; Rivera-Monroy et al. 1999; Teichert-Coddington et al. 2000; Jackson et al. 2003; Wahab et al. 2003), it is noticeable the great variability found in nitrogen loads depending on the type of culture, ranging from 31 kg N/ha cycle for extensive farms to 672 kg N/ha cycle in intensive ponds, while phosphorus loads, ranged from 11 to 33 kg/ha cycle for extensive and semi-intensive ponds, respectively. In general, it is observed that intensive shrimp ponds in Asia have a more elevated environmental load per cycle than elsewhere. These loads indicate that the environmental impact of the shrimp aquaculture is variable among farms depending of the management, location and the species involved.

A comprehensive estimation of the nutrients loads was developed for every state in the Gulf of California ecoregion (Table 2), based on the area dedicated to shrimp aquaculture (SAGARPA/ CONAPESCA 2002).

Table 2. Nitrogen and phosphorus load from shrimp aquaculture in the states around the Gulf of California.

State	N load (ton/y)	P load (ton/y)	%
Baja California	14	4	0.4
Baja California Sur	9	3	0.2
Sonora	708	193	19.5
Sinaloa	2659	724	73.2
Nayarit	242	66	6.7
Total	3632	990	100

The scenario for 2004 probably is similar or identical to 2001 due to during the last three years the aquaculture sector have experimented small changes by the reduction of the price in the international market and the presence of disease outbreaks. Comparatively, Sinaloa state provides the higher contribution of N and P from the shrimp aquaculture to the environment, while Baja California contributed with the lowest load of both nutrients. It is important to indicate that such nutrient loads are the maximum values that can attain under extreme conditions, which depends on the distance between the receiving body water and the farms, as well as the self purification processes by sedimentation, denitrification and biological uptake occurring on the surroundings of the farms, before that nutrients reach coastal or lagoon waters.

The discharge of P and N from sewage studies, calculated in terms of grams per person per day, can be used to express the mass flow of aquaculture farm effluents in population equivalents (Pillay 1992). Using the population equivalents of N and P estimated by Páez-Osuna et al. (1998) of 6 g N/day and 1.4 g P/day per person for Sinaloa, and assuming that all the shrimp farms in the Gulf of California ecoregion operate as described here, the 51,059 ha represent a load corresponding to the untreated sewage generated by 1,657,991 and 1,937,378 people in terms of N and P, respectively, discharged per year. Evidently, this has several implications for the possible expansion of shrimp aquaculture in the region and for shrimp pond management, which should increase the production efficiency and simultaneously reduce the nutrients load.

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REFERENCES

Boyd CE, Teichert-Coddington D (1995) Dry matter, ash, and elemental composition of pond-cultured Penaeus vannamei and P. stylirostris. J

World Aquacult Soc 26: 88-92
FAO (1999) Aquaculture Production Statistics 1988-1997. Fisheries Circular No. 815 Rev. 11, FAO, Rome
Jackson C, Preston N, Thompson PJ, Burford M (2003) Nitrogen budget and effluent nitrogen components at an intensive shrimp farm. Aquaculture 218: 397-411
Martin JLM, Veran Y, Guerlorget O, Pham D (1998) Shrimp rearing: stocking density, growth, impact on sediment, waste output and their relationships studied through the nitrogen budget in rearing ponds. Aquaculture 164: 135-149
Páez-Osuna F (2001a) The environmental impact of shrimp aquaculture: causes, effects and mitigating alternatives. Environ Manage 28: 131-140
Páez-Osuna F (2001b) Camaronicultura y Medio Ambiente. Programa Universitario del Medio Ambiente, UNAM, Instituto de Ciencias del Mar y Limnología, UNAM, El Colegio de Sinaloa, México, D.F. (in Spanish)
Páez-Osuna F, Gracia A, Flores-Verdugo F, Lyle-Fritch LP, Alonso-Rodriguez R, Roque A, Ruiz-Fernández AC (2003) Shrimp aquaculture development and the environment in the Gulf of California ecoregion. Mar Pollut Bull 46: 806-815
Páez-Osuna F, Guerrero-Galván SR, Ruiz-Fernández AC, Espinoza-Angulo R (1997) Fluxes and mass balances of nutrients in a semi-intensive shrimp farm in North-Western Mexico. Mar Pollut Bull 34: 290-297
Páez-Osuna F, Guerrero-Galván SR, Ruiz-Fernández AC (1999) Discharge of nutrients from shrimp farming to coastal waters of the Gulf of California. Mar Pollut Bull 38: 585-592
Pillay TVR (1992) Aquaculture and the environment. John Wiley & Sons, New York
Rivera-Monroy VH, Torres LA, Nixon B, Newmark F, Twilley RR (1999) The potential use of mangrove forests as nitrogen sinks of shrimp aquaculture pond effluents: the role of denitrification. J World Aquacult Soc 30: 12-25
SAGARPA/CONAPESCA (2002) www.sagarpa.gob.mx/pesca/anuario2001
Ruiz-Fernández AC, Páez-Osuna F (2004) Comparative survey of the influent and effluent water quality of shrimp ponds on Mexican farms. Water Environ Res 76: 5-14
Teichert-Coddington DR, Martínez D, Ramírez E (2000) Partial nutrient budgets for semi-intensive shrimp farms in Honduras. Aquaculture 190: 139-145
Tucker CS, Boyd CE (1985) Water quality. In: Tucker CS (ed) Water Quality (Channel Catfish Culture Ponds). Developments in Aquaculture and Fisheries Science, Elsevier, Netherlands, p 135-227
Wahab MA, Bergeheim A, Braaten B (2003) Water quality and partial mass budget in extensive shrimp ponds in Bangladesh. Aquaculture 218: 413-423