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Review

Shrimp aquaculture development and the environment in the Gulf of California ecoregion

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Abstract

Beginning in the middle of the 1980s, the Gulf of California ecoregion experienced a boom in shrimp aquaculture and became the second largest producer in the western hemisphere. The moderated, but continual development of shrimp farming, in conjunction with municipal and agriculture effluents has been accompanied by concern about: (a) depletion of fishing stocks, (b) reduction of mangrove forest, (c) frequent harmful algal blooms in coastal waters and shrimp ponds, and (d) water quality deterioration. We demonstrate that environmental degradation resulted from a conjunction of factors including agriculture, untreated municipal effluents, shrimp aquaculture, increasing number of fishermen, and an absence of an effective regulatory program. We recommend the immediate implementation of an integrated coastal management program to protect the integrity of the coastal ecosystems and operate upon the principle of environmental sustainability for the different economic activities including shrimp aquaculture.

Keywords: Shrimp aquaculture; Mangroves; Fisheries; Algal blooms; Water quality; Gulf of California

1. Introduction

About 97% of shrimp aquaculture ponds in Mexico are located around in the Gulf of California at the states of Baja California, Baja California Sur, Sonora, Sinaloa and Nayarit. Since 1985, there has been an expansion in shrimp aquaculture with the greatest increase in northwest Mexico so that this country has become the second largest producer of farm-raised shrimp in the western hemisphere (Páez-Osuna, 2001). This has brought concerns about the possible effects of the installation of shrimp facilities and pond effluents on coastal ecosystems. This expansion, apparently without control, has caused conflicts with other activities, such as traditional fisheries, agriculture and tourism.

The Gulf of California is a semi-enclosed sea on the Pacific coast of Mexico, one of the most biologically diverse regions in the world with approximately 6000 reported macrofaunal species (Hendrickx et al., 2002). This is a high productivity subtropical area with approximately 258,593 km^2, which is situated between the Baja Peninsula and mainland. The Gulf of California region is characterized by the presence of approximately 900 islands, 40 estuaries and lagoons. The Gulf of California ecoregion defined by the World Wildlife Fund includes the ecologically important Marismas Nacionales (National Marsh) that lies south of the Gulf proper. The Gulf and the adjacent ecosystems are populated with a multiplicity of marine mammals, birds, reptiles and a wide variety of fish and shellfish. The region supports fisheries, tourism, intensive agriculture, mining, and recently, shrimp aquaculture. These activities and the presence of around 5 millions of inhabitants constitute a serious threat to the rich and complex biodiversity of the Gulf ecoregion.

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The wet ecosystems of the Gulf ecoregion comprises a great variety of habitats that include mangrove forests, salt-marshes, intertidal pools, swamps, freshwater inner lagoons, brackish and seawater systems, where there is a rich and complex food chain. These habitats are important breeding ground for birds, fish, crustaceans, and mammals. Additionally, these ecosystems constitute important fishery grounds and favorable conditions for aquaculture; the lagoons provide nursery grounds for postlarvae shrimp as well as for commercially important fish species.The whole Gulf of California ecoregion contains substantial areas that have been considered suitable for shrimp farming; De la Lanza-Espino et al. (1993), estimated 236,000 ha of lowlands potentially available for the shrimp aquaculture for the Gulf of California ecoregion.

Shrimp aquaculture and its sustainability here has become controversial. On one hand, traditional fishermen from open sea and coastal lagoons are confronting shrimp farmers due to coastal ecosystem damages and the consequent decrease of fisheries yields. On the other hand, numerous farm owners and operators of shrimp farms report that catches of wild shrimp in both open and coastal systems have declined because of over-exploitation and contamination of the coastal zone. Shrimp farm owners indicate that the develop of the shrimp farm have been poor or moderate, due essentially to problems of land possession, lack of government stimulus, and increasing diseases.

2. Depletion of the shrimp fisheries

The shrimp fishery in the Mexican Pacific is mainly supported by three species: *Litopenaeus vannamei* (white shrimp), *Litopenaeus stylirostris* (blue shrimp), *Farfantepenaeus californiensis* (brown shrimp), and to a lesser extent *Farfantepenaeus brevirostris* (crystal shrimp) and *Trachypenaeus pacificus* (zebra shrimp). Fishing of the first two species has reached critical situation, and catches of brown shrimp and crystal shrimp are at their maximum sustainable yield (INP, 1998). Shrimp farming represents the only alternative for a substantive increment of production.

In 2001, a total of 17,487 ton and 10,586 ton of shrimp were caught by the fleet from the coasts of Sinaloa and Sonora, respectively (SAGARPA/CONAPESCA, 2002); which is 78.7% of the Mexican Pacific and 48.8% of the total for Mexico. In the last two decades, shrimp catches in Sinaloa and Sonora have declined significantly, from an average annual catch of 24,316 ton and 15,718 ton, respectively, during the 1980s, to 17,587 ton and 11,012 ton, respectively, for the 1990s (Fig. 1), i.e. a reduction of 28–30%. When global shrimp catch in the entire Gulf of California is examined, the reduction is 23.5%. This 'deficit' (10,137 ton) is worth \$65–135 millions USD.

3. Development and characteristics of shrimp farming

SAGARPA/CONAPESCA (2002) report the total area dedicated to shrimp farming is 52,648 ha, of which 51,059 ha (≈97%) are located around the Gulf of California; Baja California, 190 ha; Baja California Sur, 128 ha; Sonora, 9951 ha; Sinaloa, 37,390 ha; and Nayarit, 3400 ha (Fig. 1).

The range size of farms in the Gulf of California region vary from 4 to 1200 ha, with a mean estimated at 150 ha. The pond size also is variable (<2 and 40 ha), 2–15 ha being predominant. The more common management system in the region is the semi-intensive type which occurs in 89% of the farms, while intensive and extensive types comprise 2% and 9%, respectively. The mean stock density for intensive shrimp farms is 58 postlarvae m^{-2} (PL m^{-2}), for the semi-intensive 13 PL m^{-2}, and for extensive 7 PL m^{-2}; 39% of the farms stocks blue shrimp (*L. stylirostris*), 37% stock white shrimp (*L. vannamei*) and 24% stock both shrimp species (Lyle-Fritch et al., 2001). During 1999, in Sinaloa 74% of shrimp farms operated two cycles per year, and the rest only one. However, in 2001 and 2002 the tendency has been to reduce the number of cycles per year due to the decreased crops during cold months. The duration of the cycles fluctuates between 120 and 140 days depending on season, marketing demand, and diseases. More details on the management and characteristics of shrimp ponds are summarized in Table 1.

4. Shrimp aquaculture and mangroves

Legal aspects of mangrove conservation in Mexico are included in the regulation 059 of the Federal Law on the Ecological Equilibrium (Anonymous, 1988); white mangrove (*Laguncularia racemosa*), black mangrove (*Avicennia germinans*), and buttonwood (*Conocarpus erectus)* are under special protection, and the red mangrove (*Rhizophora mangle)* is considered as a rare species. Despite legal efforts concerning mangrove conservation, legislation on this matter is still deficient and there is a lack of enforcement.

There is significant uncertainty about the total area of mangroves in Mexico, and the magnitude of shrimp aquaculture impact on these ecosystems is unknown. However, on a regional scale, there is evidence of mangrove destruction in Sinaloa and Nayarit. The Federal Agency of Environmental Protection, PROFEPA (Procuraduría Federal de Protección al Ambiente) considers that Sinaloa has problems of shrimp fishing during the prohibited season as well as of mangrove

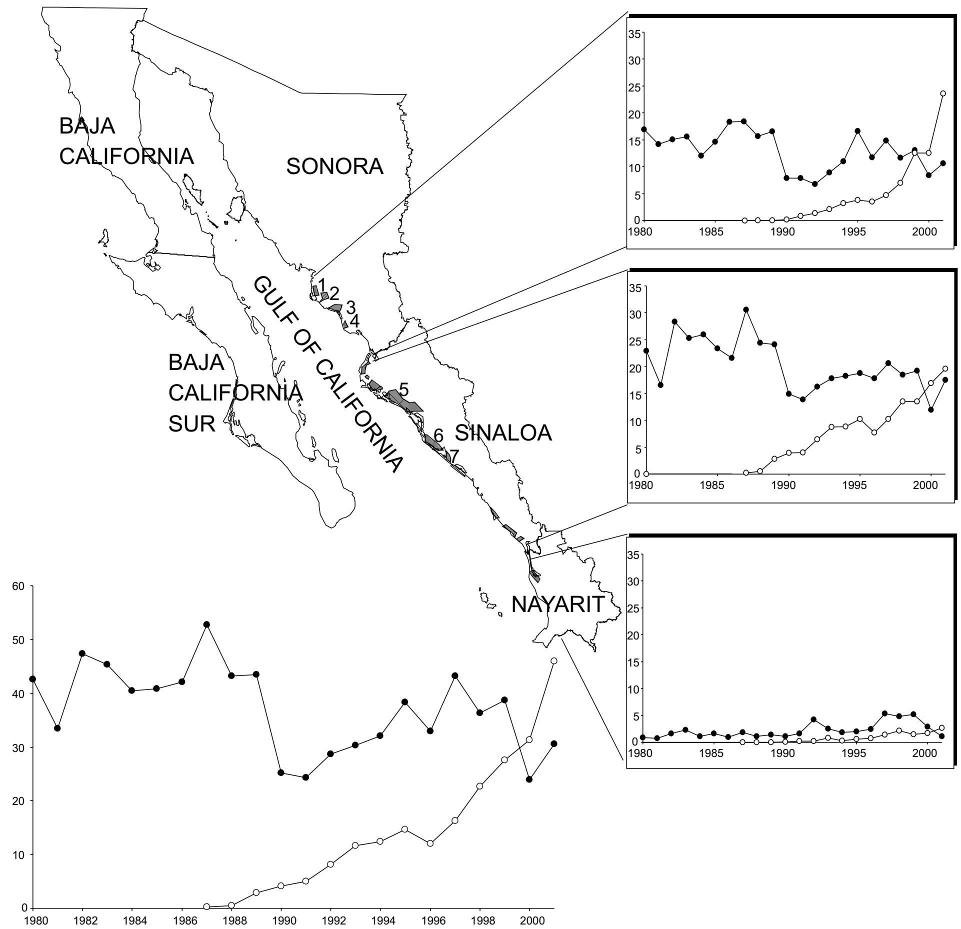

Fig. 1. Gulf of California ecoregion. Localization of zones with major density of shrimp farms (shadow areas). Tendency of the shrimp catch (filled circles) and shrimp farming (unfilled circles) production from the Gulf of California ecoregion ($\times 10^3$ ton/y) by state and globally during the 1980–2001 period (Baja California and Baja California Sur have an catch and shrimp farming <710 ton/y) (data from SAGARPA/CONAPESCA, 2002).

deforestation for shrimp farm construction. In terms of vegetation coverage, the degree of mangrove deterioration in Mexico is not as evident as in other countries. Growth of shrimp aquaculture has been moderate and mostly concentrated in seasonal flood plains.

Despite discrepancies with mangrove extension, several authors have agreed that Sinaloa and Nayarit are among the four states with more mangrove surface in the country (Flores-Verdugo et al., 1992; Tovilla, 1994). Tovilla (1994) estimated an area of 153,409 ha in Nayarit, and 74,539 ha in Sinaloa; these regions with Campeche (117,000 ha) and Chiapas (70,000 ha) comprise more than 60% of the national mangrove forest (Blasco, 1988).

In Sinaloa, development of shrimp aquaculture and other anthropogenic activities was studied, in order to assess their impact on mangrove and salt marsh ecosystems as well as on the surrounding terrestrial ecosystems. In Ceuta lagoon (Sinaloa), Alonso-Pérez (2000) observed changes of land use mainly by agriculture (141% increase from 1984 to 1999) but no mangrove damage by aquaculture was detected. Ruiz-Luna and Berlanga-Robles (1999) observed that drying lagoons in the Huizache-Caimanero system (Sinaloa), caused a 20% loss of water surface from 1973 to 1997 and an increase of the adjacent seasonal salt pans. The authors considered that the impact to the system was a consequence of a reduction of deciduous tropical forest for agricultural purposes, and a 50% decrease of mangrove forests was observed between 1973 and 1997. In addition to the elevated rate of mangrove deforestation (1.9% per year), mangrove coverage in this zone is scarce and with a patchy distribution that aggravates an unstable condition. Carrera and de la Fuente (2001) report that in Marismas-Nacionales (Nayarit) about 1456 ha of wetlands have been replaced by shrimp farm ponds.

Though digital images of mangrove impact by aquaculture have been made in Mexico and have demonstrated a non-significant perturbation, such estimations determine vegetal coverage and not forest structure in terms of density and basal area. Agraz-Hernández (1999) found that in Estero de Urías (Sinaloa) mangrove density around shrimp farms has decreased 50% in comparison with mangrove located elsewhere. In the

Table 1
Characteristics of the shrimp ponds at the Gulf of California ecoregion

Characteristics	Level of intensity		
	Extensive	Semi-intensive	Intensive
Pond size (ha)	5–100	2–25	1–4
Shrimp farm size (ha)	6–200	12–1200	42–260
Pond shape	Irregular	Rectangular or semi-regular	Rectangular
Dike construction	Earthen	Earthen	Earthen or liner[a]
Water depth (m)	0.4–1.0	0.7–1.5	1.0–2.0
Water exchange mode	Tidal	Pump and gravity	Pump and gravity
Aeration	Natural	Natural and water exchange	Aerators, water exchange and natural
Seed source	Wild	Hatchery (with or without nursery)	Hatchery
Stocking rate ($PL\,m^{-2}$)[b]	2–10	5–25	35–150
Feed	Natural (sometimes supplement)	Natural + supplement	Natural + supplement
Production (ton/ha/cycle)	<1	0.7–2.1	2.5–6
Feed coefficient[c]	Not evaluated	0.7–2.0	1.3–1.8
Fertilization	Null or very limited	Nitrogen (urea) + phosphorus (phosphoric acid or polyphosphate)	Nitrogen (urea) + phosphorus (phosphoric acid or polyphosphate)
Cycles/year	1–2	1–2	1–2
Duration of the cycles (months)	4–5	3–5	3–5
Management attention	Minimal	Continuous skilled	Continuous skilled
Labor needs (ha/person)	6–10	2–7	2–7

[a] Generally polyethylene.
[b] Number of postlarvae per m^2.
[c] Dry feed added/wet weight of shrimp harvested.

Gulf of California ecoregion mangrove forests are distributed in narrow fringes of less than 30 m width, such mangroves border tidal channels that escape image resolution (e.g. 80×80) of some satellites as well as the scales (>1:30,000) of some aerial photographs or maps. Such mangroves are particularly sensitive to changes in hydrological patterns due to their marginal distribution, and are easily displaced by a variety of human activities and natural events. Nevertheless and despite their limited distribution, in dry and semidry regions they are key ecosystems as feeding grounds and rest areas for migratory birds and as an additional energy supply for trophic chains of adjacent terrestrial ecosystems (Flores-Verdugo, 2001).

In southern Sinaloa, Ruiz-Luna and Hernandez-Cornejo (1999) showed that 4 of 19 shrimp farms have replaced mangroves. Most shrimp farms in Sinaloa are located in the central and northern regions where it is possible to find shrimp ponds that interrupt the natural distribution of mangroves. This is evidence that mangroves are being displaced by shrimp farm facilities. In the state of Nayarit, and particularly in San Blas, mature mangrove ecosystems have been destroyed during construction of shrimp ponds. The implications and magnitude of the damage are still unknown.

The main indirect impacts from shrimp aquaculture on mangroves in the Gulf of California region were:

(a) *Changes in the hydrological pattern*. Shrimp pond levees change the pattern of runoff and sometimes they interrupt seasonal streams and tidal channels affecting mangroves by altering fresh water availability and the flooding periods. Such events are particularly critical in semiarid regions of the continental margin of the Gulf of California and might induce mortality of vast mangrove zones, particularly those species under environmental stress. Levees of roads to shrimp farms and fishing sites pose a similar hazard to mangroves when they alter tidal channels. Pumping operations for water exchange in shrimp farms can cause significant changes in the hydrodynamic patterns of coastal lagoons. Additionally, an artificial rise of water levels in ponds enhances saline intrusion.

(b) *Hypersalinity*. Water evaporation in shrimp ponds has been estimated to increase 50% in comparison to natural wetlands (Twilley, 1991). With this high evaporation rate, discharges of hypersaline waters to the adjacent estuarine system are significant. Consequently, the increased salinity is particularly critical for mangroves, especially for white mangrove (*L. racemosa*) which has a high affinity for fresh-estuarine waters (Kovacs, 2000). An elevation of interstitial salinity can induce mangrove mortality (Cintrón et al., 1978).

(c) *Eutrophication*. Though eutrophication has a minor effect on mangroves, communities that live attached to their roots suffer changes in their structure and distribution. Phytoplankton and macroalgal blooms develop in tidal channels and lagoon systems. When excessive growth of macroalgae occurs, they are transported by tidal currents toward mangroves and affect colonization processes by seedlings and propagules. When macroalgae accumulate on mangrove seedlings, they block sunlight and increase the contact surface, facilitating tidal flows which remove propagules and seedlings from the soil.

In general, though mangrove impact by shrimp aquaculture in the Gulf of California region, is not as high as in other regions of Latin America and Asia, an integrated management plan for every hydrological basin is necessary in order to regulate all the activities. Flores-Verdugo (1992) and Bojórquez-Tapia (1992) propose the following ecological criteria as mitigating measures of mangrove impact: (a) Shrimp farm facilities should be developed, preferentially, in non-vegetated seasonal flood plains; (b) Infrastructure development should be based on studies of hydrological capacity, flora distribution and buffer zones. Such infrastructure should have only one road, one input stream, one drainage channel for the several shrimp farms and treatment systems for residual water; (c) About 30% or more, of the farm surface should be kept in its original condition as a buffer zone between the farm and the agriculture lands in order to avoid saline intrusion, between farms so flooding are avoided and have a free runoff from upper lands to the adjacent lagoon and from the farm and the mangroves to avoid the border effect in the mangrove forest structure and as a potential zone for colonization; (d) Reestablish the runoff pattern toward mangroves by channels surrounding ponds. Mangrove reforestation on channel sides avoid erosion. Roads should have culverts to allow tidal flows and terrestrial runoff of water.

To limit eutrophication: (i) shrimp farms should be restricted to non-vegetated seasonal flood plains and not exceed 10% of the adjacent lagoon surface until the hydrological capacity for removing nutrients without eutrophication is known; (ii) In zones with agriculture, discharge channels from shrimp ponds and agricultural lands should be connected into a single channel that carries wastes directly to the open sea, without contact with coastal lagoons, estuaries or bays. The aim of this arrangement is to integrate agriculture and aquaculture activities with ecological and economical functions of coastal ecosystems into a single management plan. Apparently, the most suitable solution to avoid coastal eutrophication is the dilution of waste discharge into the open sea (though not advisable for pesticides and other substances that are not degraded); (iii) Use of adjacent mangroves as biofilters. The capacity of mangroves to remove nutrients has been estimated as 2–3 ha of mangrove needed per one ha of semi-intensive shrimp ponds (Robertson and Phillips, 1995). For certain zones mangrove capacity is overloaded; (iv) Construction of semi natural wetlands inside aquaculture facilities. Aquaculture facilities should include ponds with filtrating organisms (bivalves) and ponds with mangroves or other aquatic macrophytes for water reuse.

5. Wild postlarvae and the shrimp fisheries

When larvae laboratories are not available or in short supply, a common source of postlarvae is direct extraction from the wild. It is generally thought among farmers that these postlarvae are more resistant because they survive better and wild seeds also have a relatively lower cost than larvae from laboratories. However, wild postlarvae supply is subject to spawning seasonal fluctuations.

On the other hand postlarvae exploitation from the environment poses a additional pressure on the shrimp resource. One view is that the effect is negligible since larval mortality is naturally high. In order to assess the impact of larvae extraction on shrimp populations, Gracia (1989a,b) analyzed simulation models based on population parameters of white shrimp. The results showed that the impact of larvae extraction was variable depending on the stage of shrimp. There is a small impact when extraction takes place at the first stages and increases exponentially in later stages, mainly in juvenile stages. Natural mortality is a critical factor too. According to the analysis, postlarvae extraction has less effect when organisms are caught in the coastal zone close to the estuaries or coastal lagoons during shrimp immigration to nursery grounds.

Once the organisms are established in the nursery areas, the negative effect has an exponential increase; as a consequence, larvae extraction during the first juvenile stages can produce a high impact on shrimp populations and hence on total production. Fishing of small juveniles produces growth overfishing (Gracia, 1995, 1997a,b), and the overall result is a decrease in total production. According to the author, total biomass reduction is higher as juveniles are younger; such fishing pressure poses risks to the optimal exploitation and the reproductive potential of shrimp populations.

Simulation analyses indicate that larvae extraction has an impact on shrimp populations; the degree of the impact depends on the fishing effort and the age of specimens. The effect on shrimp populations is proportional to the number of larvae that are extracted for farming purposes; however, it could be minimal if extraction was carried out during the stages of high mortality incidence, i.e. before larvae enter breeding areas to settle. Shrimp exploitation during this stage is based on the strategy of minimal loss due to natural mortality (Watt, 1968). From this approach, the result would be that organisms that would die from natural mortality would be used.

The application of this should consider several features of shrimp populations related to biotic and abiotic components of natural mortality, reproductive strategies and any effects of accumulated mortality throughout shrimp life cycle. An accurate estimation of the natural mortality is a basic requirement (Gracia, 1995), and a bias in the estimation of this parameter has important consequences in fisheries management (Gracia, 1989b). In the case of postlarvae and juvenile stages the problem is more complicated as reliable estimations of natural mortality are scarce, so this parameter is considered to be high (without considering the effect of migration). According to Alvarez et al. (1987) juvenile migration in a given area can bias mortality by around 25%. When this bias is not considered, it could influence calculations on shrimp extraction and management strategies.

Nowadays, larvae extraction in Mexico is legal through regulation on their exploitation exist. Rules are contemplated within Shrimp Mexican Official Norm (Norma Oficial Mexicana de Camarón) 002-PESC-1993, and comprises shrimp species in Mexican waters; Section 4.4 refers to regulation applicable to shrimp species in their natural environment (larvae and postlarvae stages) that are currently used for the development of aquatic activities. Among these rules are: larva and postlarvae catching can be authorized in (a) beach fronts, with the exception of those beaches next to zones of water exchange between the sea and lagoon systems and bays; (b) zones with temporal flooding; and (c) zones where shrimp larvae and postlarvae have little chances to survive.

From the above statement, the general concern on how increased shrimp farming could affect renovation of the shrimp population is relevant. Current Mexican legislation to control impacts are useful; however, key aspects to consider are the observance of fishing areas and avoidance of extraction of benthic postlarvae. In this sense, the maximum size for collection (20 mm) should be smaller because at this size postlarvae have already enter the nursery areas.

Another aspect that deserves attention is related to the side effects of postlarvae extraction on other components of planktonic communities. No studies on plankton bycatch exist. However, the lack of information makes it difficult to give a sound opinion based on scientific knowledge.

Another concern related to shrimp aquaculture and fisheries has appeared; fishermen claim that pumping water transfers postlarvae to shrimp ponds causing an additional impact on wild shrimp populations and consequently on shrimp landings. Considering the number of farms and the amount of water pumped, it is obvious that some postlarvae could be carried into the ponds; however, there is no scientific evidence that this activity is affecting shrimp fisheries. First, this extraction would take place at postlarvae age where the impact on the fishery is minimal. Moreover, postlarvae distribution patterns offshore, and nursery ground immigration behavior, make it unlikely. Postlarvae distribution is not homogenous in time and space and it is known that they concentrate near lagoon and estuary inlets. Also, immigration mechanisms are based on tidal movements combined with postlarvae vertical migration. Postlarvae can remain near the bottom to avoid being carried offshore when the tidal current is offshore and move higher in the water column during the opposite direction to enter estuaries and coastal lagoons (Macias-Regalado, 2001). However, as in the above case, further observations are needed to give a sound opinion about a possible effect derived from pumping water on the fisheries production.

6. Harmful algal blooms and shrimp farming

Most species of microalgae and many algal blooms are beneficial for aquaculture; they provide a small but essential part of food indirectly to the rest of the food chain in the shrimp ponds. Under favorable environmental conditions, some microalgae species produce harmful algae blooms (HABs) that can damage shrimp by consuming the oxygen in the water or producing toxins (Alonso-Rodríguez and Páez-Osuna, in press). In shrimp farms from some areas of the Gulf of California, the observed effects were morbidity, mortality and a delay in the growth of shrimp that turn into an economic loss (Cortés-Altamirano and Licea-Durán, 1999).

In Mexico, many of the most important ports and coastal towns are beginning to show symptoms of eutrophication. Red tides are common in the Gulf of California, and especially frequent in: Kino Bay, Guaymas Bay, Angel de la Guarda Island, Yavaros Lagoon, Topolobampo port and Mazatlán Bay (Cortés-Altamirano and Núñez-Pastén, 1992). The photosynthetic ciliate *Mesodinium rubrum* causes most red tides and their presence has been associated with upwelling, and is absent when El Niño events appear. The main toxic species found in 94 red tides studied in the Gulf of California were the dinoflagellates *Gymnodinium catenatum* and *Gonyaulax polyedra* (= *Lingulolidium polyedrum*) (Cortés-Altamirano et al., 1996).

During 1989–1991 several studies in two shrimp farms from northern and southern Sinaloa found algae that are considered to be harmful or toxic for shrimp (Cortés-Altamirano et al., 1994; Gárate-Lizárraga et al., 2002a). The most abundant specimens were cyanobacteria *Anabaena* spp., *Anabaenopsis elenkinii* and *Oscillatoria limnetica*; they colonize superficial waters and block light penetration that results in eutrophic conditions at the bottom of the ponds. Also, some dinoflagellates frequently observed are *Prorocentrum minimum*, *Gymnodinium* spp., *Gyrodinium* spp. and *Protoperidinium trochoideum* (= *Scripssiella trochoidea*). P. *minimum* is considered a toxic species whose abundance is promoted by humic acids and inadequate fertilization (Cortés-Altamirano et al., 1994). Other studies conducted in three shrimp farms in Sinaloa during 1990–1993 found that *Synechocystis diplococcus*, a non-toxic cyanobacteria, was frequently observed. Algal bloom duration ranged from 1 to 10 days; dominant species were the cyanobacteria *A. elenkinii*, *Schizothrix calcicola* and *Anabaena aequalis*, and the dinoflagellates *P. minimum*, *Gymnodinium incoloratum*, *Gyrodinium spirale* and other species of the genus *Gyrodinium* (Cortés-Altamirano and Licea-Durán, 1999). Several common factors were considered to be responsible for algal blooms: inadequate fertilization, excretion of substances that promote growth of microalgae and environmental conditions. In one farm, shrimp weight was lowered because of a *S. calcicola* bloom associated with strong rains.

Water effluents from shrimp farms, in addition to municipal, agricultural and industrial wastewater, are discharged directly to coastal waters from the Gulf of California; such discharges are not subjected to previous treatment. Knowledge of how shrimp pond effluent affects coastal waters, and how it affects aquaculture activities is just beginning. In Sinaloa, winter-spring red tides have occurred along the coast leading to red-tides episode within shrimp ponds. Toxicity studies during these blooms (Cortés-Altamirano and Alonso-Rodríguez, 1997; Gárate-Lizárraga et al., 2002b) revealed toxicity below permissible limits (>80 MU g oyster tissue) for human consumption of shellfish, consequently, it is necessary to evaluate if this toxicity is enough to provoke death of shrimp in larvae and adults.

The main problem for sustainability of shrimp culture in Sinaloa is the maintenance of good water quality in the adjacent coastal region. The difficulty assessing the impact of its discharges on receiving water bodies rises from a lack of communication among farms, scientific and governmental authorities and the lack of long-term. More details on the phytoplankton and HABs on the situation in the Gulf of California ecoregion are given in Alonso-Rodríguez and Páez-Osuna (in press).

7. Diseases and antibiotics

The link between diseases and water quality seems to be more and more obvious. Stress caused by sub-optimal environmental conditions induces adverse organism responses. Although aquatic organisms may seem healthy during and immediately after a period of stress, a disease outbreak or a chronic mortality event may develop in the stressed population. Many of these organisms can be as symptomatic carriers of a pathogen which under normal conditions does not express itself.

The bacterial communities present in ponds are susceptible to fluctuations and interactions from physicochemical factors (pH, temperature, dissolved oxygen, etc.). A correct feeding regime and also the generation of good algal blooms are important to maintain the water quality and the balance of the bacterial communities, since they are the main source of organic matter for the system. An excess of organic matter in the system can induce an accelerated development of the bacterial communities in the pond. This high organic matter and bacteria present cause a higher demand of oxygen in the pond bottom, which affect negatively the shrimp population.

A number of infectious diseases have been described in farmed shrimp. In the Gulf of California ecoregion, the most common parasitic diseases are "cotton shrimp", caused by microsporidea, and gregarines, of which 3 genera affect shrimp, *Nematopsis, Cephabolus* and Paraophioidina. Several fungi have also been found to be shrimp pathogens, some more common in larval stages and others in juvenile and adult stages. The most common genus found in larvae is *Lagenidium*, while in juveniles and adults, *Fusarium* causes more problems.

Around 20 viruses have been reported to affect cultured and wild shrimp (Lightner and Redman, 1998). The most important ones have been White Spot Syndrome virus, Infectious Hypodermic Haematopoietic Necrosis virus and Taura Syndrome virus. It is important to keep in mind that shrimp are potentially very susceptible to environmental contamination, mainly due to insecticides due to their close phylogenetic relationship with insects, so water quality problems lead to disease outbreaks. In the case of bacterial diseases, vibriosis is most frequent disease, both in larviculture and growout. Vibriosis can be defined as an infection caused by bacteria belonging to the genus *Vibrio*. In larval systems, bacteria have been considered the biggest cause of mortality. However, it is important to emphasize that up to now, diseases reported in larviculture are caused by opportunistic bacteria, which affect larvae when they are weakened by an environmental factor. In fact, most *Vibrio* species have been associated with diseased shrimp, however this does not imply that they are the main cause of disease, but that due to their opportunistic behavior, they proliferate inside weakened shrimp. Historically, *Vibrio parahaemolyticus, V. alginolyticus, V. vulnificus and Listonella damsela* have caused problems in growout ponds, whereas *V. harveyi* and *V. splendidus* have caused problems in larviculture. However these species have also been found in the haemolymph and hepatopancreas of healthy juveniles of *L. vannamei* (Gómez-Gil et al., 1998).

In a survey of 23 shrimp farms in Sinaloa during 2002 (Lyle-Fritch and Romero-Beltrán, 2002) it was found that 18 of 23 farms suffered one or more diseases, the most frequent being caused by gregarines (13 of 23), white spot virus (10 of 23) and vibriosis (7 of 23). The WSSV was detected in the Gulf of California region from 1999, and in conjunction with vibriosis cause the biggest losses.

Often bacterial diseases are treated using antibiotics. To evaluate the impact of their use the first thing to know is the patterns of use of the antibiotics. Another factor to take into account is the hydrology of the area and water physicochemical conditions. Theoretically, the final destination of antibiotics applied in aquaculture can be non-target organisms, water, suspended solids and sediments. When antibiotics are present in the water column, they can select for resistant bacteria. The main effect that antibiotics have on the suspended solids in the water column is that they reduce the number of bacteria adhered to these solids, reducing the feed availability to the meio and macrofauna which feed on them (Weston, 1996). Antibiotics also contribute to the selection of resistant bacteria. Concerning the presence of antibiotics in the sediments, these may affect, for example, their microbial capacity to reduce sulfate, increasing the presence of sulfides.

Antibiotic resistance poses several risks. The transference of resistance genes directly to bacteria that infect humans can also happen, with a consequent increment in the incidence of infections caused by resistant pathogens, leading to an increment in therapeutic failure in both humans and animals.

In clinical terms, there is wide evidence that fish bacterial strains resistant to antibiotics developed due to the use of those antibiotics in fish disease control. However, the differences among methodologies employed by different diagnostic laboratories often mask these changes. Lastly, the isolated strains represent only a fraction of the existing bacteria in the system, the one capable of growing in the culture media being used. Perhaps induced changes are much bigger than they are thought to be. In Sinaloa, it was found (Lyle-Fritch and Romero-Beltrán, 2002) that 82.6% of the farms use food incorporating antibiotics; oxytetracycline being the most applied (67%). Other antibiotics supplied are enrofloxacin, norfloxacin, florafenicol and sarafloxacin.

During 2002, rules were established that include requirements and measures to control disease outbreaks and for the use and application of antibiotics (Norma Oficial Mexicana NOM-EM-05-PESC-2002). Among these rules are: Section 4.11 refers to role of the sanitary agency to determine the procedure required for the harvest when diseases are confirmed. Section 4.13, prohibits use chloramphenicol and furazolidone (nitrofurans) in shrimp farming. Section 4.14 prohibits treatment with antibiotics 30 days before the harvest.

8. Water quality deterioration

Despite its importance, little is known about the water quality in coastal areas of the Gulf of California; however, there are two identified issues of major concern: pesticides and nutrient overload related to agricultural runoff and raw municipal sewage discharges. There is an important development of intensive agriculture bordering the eastern coast of the Gulf of California, with approximately 1,728,868 ha of irrigated lands (Anonymous, 1994), distributed in the valleys Mexicali, Yaqui, Mayo, del Fuerte y Culiacán, in which considerable amounts of fertilizers and pesticides are applied. In a previous study carried out in the Pacific coast of Mexico (Páez-Osuna et al., 1998, 2002) using bivalve mollusks as biomonitors, it was found that in lagoons of Altata-Ensenada del Pabellón and Navachiste, Sinaloa which are surrounded by agricultural lands, the soft tissue of oyster *Crassostrea corteziensis* had concentrations of up to 216 $\mu g\, g^{-1}$ of Cu and 655 $ng\, g^{-1}$ of PCBs, respectively. From 22 organochlorine compounds detected in this study, the pesticide most frequently found and which exhibited the highest concentrations was HCB, which can be used alone or in combination with other fungicides in mixed protectants for seeds, or which can be present as an impurity of the synthesis of other several herbicides and pesticides. High HCB concentrations were found in oysters from those regions bordered by extensive agricultural lands: Yavaros (911 $ng\, g^{-1}$) and Navachiste (183 $ng\, g^{-1}$) lagoons.

Nutrient over-enrichment is another pervasive contributor to the degradation of the coastal ecosystems in the Gulf of California. The degree of nutrient impact varies among the coastal bodies, depending on factors including shallowness, high stratification or long residence times. Agriculture, shrimp farms and human wastes, are the main land-based nutrient sources of the region; however, Páez-Osuna et al. (1999) have identified agriculture as the dominant one, with an estimated annual input of 26,119 ton of P and 49,356 ton of N derived only from Sinaloa and Sonora. There are around 5 million inhabitants around the gulf; only a very few of the coastal cities have sewage treatment plants and most of them have been designed to simply reduce the amount of solids and organic matter content in the waste waters. Assuming that (a) the nutrient load associated with municipal sources is 1.4 $g\,P\,day^{-1}$ and 6 $g\,N\,day^{-1}$ per person and (b) the drainage area has the capacity to reduce this load by self-depuration by 25% for P and 50% for N (Páez-Osuna et al., 1998), the estimated annual input from municipal sources would be around 5475 tons of N and 1900 tons of P.

Shrimp farm water supply can be achieved either by open seawater structures or through small natural channels ("esteros") that connect the shrimp facility with an estuary or a coastal lagoon, as frequently occur in Sinaloa and Nayarit. Pond water is continuously exchanged (3–20%) and drained through an effluent ditch that, later on, brings back the waste water to the coastal body (Páez-Osuna et al., 1997). Considering a scenario with approximately 26,050 ha of shrimp farms in operation, Páez-Osuna et al. (1999) estimated a load of 834 ton P/y and 2900 ton N/y. Considering a scenario of 51,059 ha (SAGARPA/CONAPESCA, 2002) for the entire region around the Gulf of California, and considering previous assumptions, it is estimated that a load of 1600 ton P/y and 5700 ton N/y, is input, which represents an amount comparable to municipal loads but significantly less than agricultural discharge.

Fisheries, tourism and shrimp farming to a great extent depend on the quality of the environment, which can be easily degraded by agriculture, municipal and industry wastes. Since these activities, together with agriculture, are currently the most important factors for the economic development of the Gulf of California, an integrated coastal management program is justified and urgent.

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