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Review

Diagnosis of the current state of aquaculture production systems with regard to the environment in Mexico

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ABSTRACT. Mexican aquaculture production systems have been analyzed here in areas of the Pacific, Gulf of Mexico, and the Caribbean Sea. The species that are developed in aquaculture systems are: oysters (*Crassostrea gigas, Crassostrea corteziensis)*, abalone (*Haliotis fulgens*, *Haliotis rufescens*), clams (*Panopea generosa*), shrimp (*Litopenaeus vannamei)*, prawn (*Macrobachium rosenbergii*), tuna (*Thunnus thynnus*), tilapia (*Oreochromis niloticus*), carp (*Cyprinus carpio*), trout (*Oncorhynchus mykiss*), catfish (*Ictalurus punctatus*), and bass (*Micropterus salmoides*). There are also other species, obtained by fisheries, used to develop aquaculture production systems. From the total aquaculture production units (APU) in the southern Gulf of Mexico, 62% were identified as units engaged in tilapia culture and 38% in fattening and breeding. This is a risk and may increase the impact on aquatic ecosystems by effluents generated by these aquaculture activities. These effluents contain different components, among which are organic matter, nitrogen, and phosphorus. There are different studies for the treatment of these effluents, but are little applied to real scale, as they are performed at laboratory level. It is required to apply and obtain functional technology for producers of aquaculture systems in order to avoid the impact to ecosystems and also keep these chemical and biological hazards away from aquatic environments.

Keywords: aquaculture production units (APU), environment impacts, aquaculture effluents.

Diagnóstico del estado actual de los sistemas de producción acuícola con respecto al medio ambiente en México

RESUMEN. Se analizan los sistemas de producción acuícolas mexicanos en las áreas del Océano Pacífico, Golfo de México y Mar Caribe. Las especies que se desarrollan en cultivos acuícolas son: ostras (*Crassostrea gigas, Crassostrea corteziensis)*, abulón (*Haliotis fulgens*, *Haliotis rufescens*), almeja, (*Panopea generosa*), camarón (*Litopenaeus vannamei)*, langostino (*Macrobachium rosenbergii*), túnidos (*Thunnus thynnus*), tilapia (*Oreochromis niloticus*), carpa (*Cyprinus carpio*), trucha (*Oncorhynchus mykiss*), bagre (*Ictalurus punctatus*) y lobina (*Micropterus salmoides*). Otras especies que se obtienen por medio de la captura, son las utilizadas para su desarrollo en sistemas de producción acuícolas. En la región sur del Golfo de México del total de las unidades de producción acuícolas (UPA), el 62% se tienen identificadas como unidades que se dedican a la engorda de tilapia y el 38% a su engorda y reproducción. Lo anterior es un riesgo y puede incrementar el impacto en los ecosistemas acuáticos por los efluentes que se generan por estas actividades acuícolas ya que contienen diferentes componentes, entre los que destacan materia orgánica, nitrógeno y fósforo. Hay diferentes estudios para el tratamiento de estos efluentes, pero son poco aplicados a escala real, ya que son realizados a nivel de laboratorio. Se requiere obtener y aplicar tecnología funcional para los productores de unidades de producción acuícolas con el objetivo de evitar el impacto a los ecosistemas, principalmente los riesgos químicos y biológicos al medio acuático.

Palabras clave: unidades de producción acuícolas (UPA), impactos ambientales, efluentes acuícolas.

Aquaculture is at a global level the most dynamic food sector, experiencing an annual average growth rate of 8.8% over the past three decades (Rodríguez & Flores, 2014). On a global basis, aquaculture has increased its social and economic impact through food production, contribution to livelihoods and income generation (FAO, 2011).

In its most recent analysis of 2014, the FAO notes that aquaculture production continues to increase, albeit at a slowing pace. According to the latest available sta-

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tistics collected worldwide by the FAO, aquaculture production reached a historical record of 90.4 million ton (live weight) in 2012, which represented a total of US$144.4 billion, including 66.6 million ton of fish for human consumption worth US$137.7 billion and 23.8 million ton of aquatic algae equal to US$6.4 billion.

In addition, some countries also collectively reported production of 22,400 ton of non-food products up to US$222.4 million, such as beads and seashells for ornamental and decorative use. For this analysis, the term "fish for human consumption" is used, which includes finfish, crustaceans, mollusks, amphibians, freshwater turtles and other aquatic organisms such as sea cucumbers, sea urchins, sea squirts and jellyfish which are produced for human consumption.

According to the latest information, FAO estimates that global food production by fish aquaculture grew by 5.8%, which made a total of 70.5 million ton in 2013. In the same year, it is also highlighted the production of cultured aquatic plants particularly for seaweed, which was estimated at 26.1 million ton. China achieved an aquaculture production in 2013 of 43.5 million ton of fish for human consumption and 13.5 million ton of seaweed (FAO, 2014).

In Latin America and the Caribbean, the main producing countries in the region are Chile, Brazil, Ecuador, and Mexico, followed by Perú, Colombia, Cuba, and Honduras. In some countries like Mexico and Brazil aquaculture production for the domestic market is significant, while in others such as Chile, Ecuador, Colombia, Honduras, Costa Rica, Perú and Panamá, predominate production for exports (OLDE PESCA, 2009).

Aquaculture is performed at various scales in virtually all countries in the region. In that sense the small-scale aquaculture with limited resources, also called family aquaculture or rural aquaculture, is practiced by over 100 thousand families in Latin America and the Caribbean (Flores, 2012) helping to strengthen food security and surmounting poverty. The aim of this study is to show the analysis of the current state of fisheries and aquaculture production in Mexico and their impact on the environment.

Aquaculture in Mexico

Aquaculture is one of the most promising activities and development in recent years in Mexico, which brings social and economic benefits that result in a source of food for the population with a high nutritional value and affordable costs. However, the development of aquaculture activity has not been sufficient (Álvarez *et al*., 2012).

White shrimp (*Litopenaeus vannamei*) is grown in northwestern Mexico; these species are highly appreciated in national and international markets for its high nutritional value and its taste. Additionally, the region of northwestern Mexico, is known for its mollusks of high commercial value, such as Lion's paw scallop (*Nodipecten sunodosus*), pearl oysters (*Pinctada mazatlanica*, *Pteria sterna*), abalone (*Haliotis fulgens, Haliotis rufescens*) and scallops (*Atrina maura*) (Avilés & Vázquez, 2006).

Tilapia (*Oreochromis niloticus*) is among the most successful extensive fish culture in Mexico. Tilapia has been disseminated in a wide variety of water bodies in different regions of the country, what has allowed establishing important markets derived from this aquaculture; tilapia culture accounts for over 60% of the nation's production (Apún *et al*., 2009). The development of aquaculture in Mexico is framed in the General Law of Sustainable Fisheries and Aquaculture, which sets out the principles to order, promote, and regulate the integrated management and sustainable use of this productive activity. Additionally, the activity is subject to other federal regulations contained in the General Law of Ecological Balance and Environmental Protection, National Water Law, Regulations of National Water Act, and the Federal Law of Rights. They establish the obligation to have an environmental impact assessment prior to the implementation of the project, granting water use, and water treatment works prior to the discharge of water in order to prevent contamination of receiving water bodies (Velasco *et al*., 2012).

The Mexican Pacific

Some of the species that have been cultivated through aquaculture are: shrimp (*Litopenaeus vannamei*), oyster (*Crassostrea gigas*, *Crassostrea corteziensis*), tilapia (*Oreochromis niloticus*), largemouth bass (*Micropterus salmoides*), carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), clam (*Panopea generosa*), abalone (*Haliotis fulgens*, *Haliotis rufescens*), tuna (*Thunnus thynnus*), prawn (*Macrobachium rosenbergii*) and trout (*Oncorhynchus mykiss*)

Abalone by volume is positioned 49th of fish production in Mexico; from 2004 to 2013 abalone fisheries decreased from 647 to 479 ton. It also ranks 9th among the species exported, with the United States as main destination. The production of abalone, in aquaculture systems, is developed on the peninsula of Baja California. Its production was increased from 64 to 68 ton during the years 2012 to 2013. Clam is in 14th place in fish production in Mexico. Clam fishery had increases and decreases during the years 2012 and 2013, the largest capture happened in 2006 with 27,930 ton. Aquaculture farming of this species is mainly developed in the states of Baja California, Sonora, Sinaloa, Nayarit, and Guerrero. During 2012 and 2013 there was an increase in production through aquaculture systems for clam, with quantities of 325 to 370 ton. Tuna *(Thunnus thynnus)* capture is the largest fishing production in Mexico, ranks 2nd in terms of volume, it is the product of the states that make up the region of the Pacific in the Peninsula of California, the year of the highest fish capture was reported in 2005 with 151, 696 and 146,744 ton of this species were obtained in 2013.

Shrimp aquaculture production has grown increasingly over fish capture at sea, estuaries, and bays. Shrimp farming is done in the states of Baja California Sur, Sonora, Sinaloa, Nayarit, Colima, Guerrero, Oaxaca, and Chiapas. Tilapia production has grown regarding fish capture in states located in the Pacific, such as Sinaloa, Nayarit, Jalisco, Michoacan and Chiapas. It is worth mentioning that during 2013, 96,287 ton of tilapia was produced in Mexico. The production of oyster (*Crassostrea* spp.) in aquaculture systems in the states of Nayarit, Baja California, Guerrero, Sinaloa and Oaxaca, decreased from 43,567 ton in 2012 to 38,715 ton in 2013. Regarding oyster fishery capture, 2,401 ton was obtained during 2013. Trout farming systems in the Pacific are registered in Michoacán and Oaxaca, in areas of temperatures below 21ºC, so the trout development and growth can be carried out. Moreover capture fisheries is the most relevant for this species, since maximum values of 10,486 ton of trout were recorded during the years 2004 to 2013. Aquaculture production systems decreased from 7,026 ton in 2012 to 6,700 in 2013 (CONAPESCA, 2013).

Central and northern states

The states that are at the center of the country and therefore have no coastline are Mexico, Hidalgo, Puebla, Morelos, Zacatecas, San Luis Potosí, Guanajuato, Querétaro, Coahuila, Durango, Chihuahua, Tlaxcala, Aguascalientes and Nuevo León. The State of Hidalgo makes aquaculture production of tilapia (*Oreochromis niloticus*) and carp (*Cyprinus carpio*). Furthermore, trout farming takes place in the states of Mexico, Puebla, Hidalgo, Chihuahua and Durango, while carp production is done in Mexico and San Luis Potosí.

Tilapia is a noble culture and broad resistance to attack by pathogens species. It gets used to different environments such as rivers, streams, coastal lagoons, salt water, dikes, and ponds. The success of carp culture is that it easily adapts to different conditions of water bodies due to it withstands low oxygen concentrations, wide temperature range, besides its low dietary requirements which gives the producer an adequate and simple management.

Catfish and largemouth bass are grown in the State of Hidalgo, the first is important in sport-recreational activities in Mexico and other countries. It has an elongated body, scaleless skin and spots on the sides. The bass is a freshwater fish, which lives in temperate and tropical waters, in either dams or channels with muddy bottoms and abundant vegetation, it adapts easily to a variety of environmental conditions (SEDAGRO, 2015).

Gulf of Mexico and Caribbean Sea

The Gulf of Mexico is a semi-enclosed basin shared by Mexico and the United States of America (USA). There are extremely important settlements in it that generate high critical environmental pressure due to industrial activity of terrestrial, fluvial and maritime transport of five USA territories: Florida, Alabama, Mississippi, Louisiana and Texas, plus five Mexican states: Tamaulipas, Veracruz, Tabasco, Campeche and Yucatán.

The oyster *Crassostrea virginica* fishery is a major productive activity in the Gulf of Mexico. Veracruz State contributes with 45% of total production (SAGARPA, 2004, 2006). Aquaculture production of this species is developed in Veracruz, Tabasco and Tamaulipas. In the CONAPESCA statistical yearbook mentions that during 2012 and 2013, a production of 43,567 and 38,715 ton in oyster culture systems were obtained. Studies of biological contamination have been conducted in this species, and reported as the result of anthropogenic activities that have impacted the quality and safety of the product (Lango *et al*., 2013).

Clam production is developed in the states of Veracruz and Tabasco where in 2013, a capture of 2,409 ton were obtained. Species that are mainly developed are: Atlantic rangia (*Rangia cuneata*), which has greater commercial value; brown rangia (*Rangia flexuosa*) and carolina marhs clam (*Polimesoda carolineana*), all these in the State of Veracruz, whose production in aquaculture systems was 325 ton in 2013 and 370 ton in 2014.

Shrimp culture (*Litopenaeus vannamei*) is performed in the states of Tamaulipas, Veracruz, and Campeche. Compared with capture fisheries, shrimp aquaculture has impacted most, featuring a maximum value of 133,282 ton in culture systems in 2009.

Tilapia (*Oreochromis niloticus*) culture systems are also developed in the states of Veracruz, Tabasco and Tamaulipas. Aquaculture production units have increased, reaching a volume of 67,839 ton in recent years. Trout (*Oncorhynchus mykiss*) grow at temperatures below 18°C, so that in the State of Veracruz this species takes place mainly in areas of high mountains.

In Tamaulipas, as in the central states of the country, catfish and bass are also grown. Catfish inhabit low-flow water with gravel, rock, or sand bottom; they do not mind living in clear or turbid waters with submerged or emergent vegetation, but avoid dense vegetation. It is a nocturnal species so it looks for shelter during the day in the deep part of the reservoirs. It is an omnivorous species, in captivity accepts artificial food. It reaches a weight of 200-350 g in a time of 8-12 months, depending on environmental conditions and food availability. Bass is used as biological control of rich populations, such as tilapia, reaching a weight of 250-300 g in a period of approximately 8-10 months. This species is operated in semi-intensive culture in rustic ponds and extensive in dams or lakes for sport and/or as biological controllers. Water temperature in these crops should be between 15º and 28°C (SEDAGRO, 2015).

Environmental impacts due to wastewater from aquaculture production systems in Mexico

Freshwater aquaculture production systems are mainly dedicated to cultivate tilapia. The infrastructure in which is done varies from geomembrane, concrete or rustic ponds to cages and floating ponds. The source of water used for production comes from wells, ponds, springs, or rivers. Culture production of this species range from one to two cycles, each cycle lasts from 5 to 6 months. Among the tilapia farms, 62% are engaged in fattening and the remaining 38% in fattening and breeding. The semi-intensive farming production is 83%, of which 14% is carried out intensively and only 3% is done extensively.

Since the existing surface water sources are widely contaminated, groundwater is the main source of fresh water for aquaculture. Consequently, several areas have faced land subsidence as a result of excessive groundwater extraction. Furthermore, the accumulation of food waste and fish feces during cultivation often causes deterioration of water quality in fishponds, resulting in toxic effects to fish. Discharges from fish farms contain significant amounts of organic matter, nitrogen, and phosphorus and can degrade even more the water quality in receiving waters. Therefore, it is apparent that an appropriate wastewater treatment process is helpful for sustaining aquaculture development (Ying *et al*., 2002).

Food supply is the main cause of deterioration of water quality. The amount of nutrients in ponds is not fully exploited and when fishing, water with high organic matter is released into rivers or natural water bodies (Boyd, 1992). In many systems of fish production in ponds, only 30% of the supplied nutrients are converted into product, the rest is accumulated in sediments or released in the effluent (which usually goes into rivers) (Acosta *et al*., 1994; Gross *et al*., 2000).

Many factors of farming systems that impact on biodiversity are common. However, in aquaculture by virtue of the medium in which farming is based pose additional entities, principally through the connectivity of the water sheds, across geographical terrains and geo-political boundaries. This connectivity often makes it harder to impose controls when and where needed on spread of a translocated species and or a pathogen/ disease for example (De Silva, 2012)

Pollutant concentrations in groundwater were determined out of surface wells or water well in aquatic farms located along the river, and in lagoon systems, located in the State of Veracruz, Mexico, and their possible risks for human health. Concentrations of nitrates, total coliforms and *Vibrio* sp. were determined as well as temperature, salinity, dissolved oxygen and pH. The results were beyond the permissible limits established by Mexican standards. The resulting contamination is a risk to human health, particularly for water extracted from aquifers, since chemical and microbiological contaminants are transmitted to man through the consumption of unsanitary water, domestic activities, or when it contaminates aquatic organisms in aquaculture or other fisheries. This consumption can lead to acute or chronic human disease (Landeros *et al*., 2012).

Moreover, the main environmental impacts, for which aquaculture has been blamed, must be taken into account, in order to avoid them and promote their sustainable development. The occupation of coastal areas may become critical and the use of water resources will become increasingly being disputed, due to industrial, agricultural and domestic consumption uses. Thus, it is highlighted the importance of planning the use of land and resources with respect to space occupation, especially coastal and adjacent areas to bodies and watercourses, since it is crucial to avoid conflicts with other users; who are on the rise due to population growth. Moreover, the use of large volumes of water by aquaculture motivates managers of sustainable development to demand that the necessary actions must be taken to achieve the most rational use of water. Noting that when properly performed, aquaculture is no threat of pollution as other human activities, but always considering avoiding any form of contamination. One of them is altering the environment and landscape (varies according to the type of aquaculture); it has also been cited as a negative impact, so it must be prevented. These impacts are mainly concern to: destruction of habitats (mangroves, coastal lagoons); involvement in agricultural areas, urban or tourism; input of organic matter and disposal of solid; discharge of nutrients (P, N, NH_3) and chemical waste; changes in waterways or flow restrictions or access to them, and generation of noise, odor, and traffic. Another actual or potential aquaculture negative impacts refer to the introduction of species (most of aquaculture is based on introduced species), which can cause problems in new habitats by competing with native species, affecting natural resources and artisanal fishing, hybridization, and especially the spread of disease. Therefore, all new introductions outside its area of origin must be practiced with biosecurity measures and specific control. Furthermore, although 80% of the global aquaculture production is based on herbivorous species, one aspect that motivates most controversy refers to the use of marine species in the diet of other aquaculture species through the production of fishmeal and oil (OLDEPESCA, 2009).

Cage production systems have shown that a significant impact, within a kilometer around, the culture cages can sometimes be detected. This, being generally higher in the seabed, where it can be observed among other effects, increase oxygen demand, production of anoxic sediments and toxic gases, changes in communities, decreased benthic diversity, changes in biodiversity, development of resistant species to pollution which can be harmful to the cultivated species, and phytoplankton blooms (Soto & Norambuena, 2004).

Technologies used to treat effluents from aquaculture production systems

A number of physical, chemical, and biological methods have been applied to the treatment of wastewater from aquaculture systems. Solids removal is performed by sedimentation, sand filtration, or mechanical filtration. Biological processes such as submerged biofilters, trickling filters, rotating biological contactors and fluidized bed reactors are used among others for the oxidation of organic matter, nitrification, and denitrification (Van Rijn, 1996).

Biofiltration

Three commercially available biological filters were evaluated, based on a production system of tilapia culture. The first filter was the Clearwater, model LSB25 filled with Kaldnes media. The second filter, a PolyGeyser floating bead filter, Model DF15, filled with polyethylene floating beads and the third filter, a CycloBio fluidized sand biological filter with media of silica sand. Total ammoniacal nitrogen (TAN) rates were determined for the three types of biofilters for a range of concentrations ranging from 0.13 to 1.20 g TAN m^{-3}. Feed rates and ammonium chloride additions were varied according to fish feeding response. Maximum feed rates were 65 kg feed day^{-1} using 40% protein diet at a maximum biomass of 5,500 kg. Average observed TAN removal rates (media ± standard deviation) for the three filters were 267 ± 123 gTAN m^{-3} day^{-1} (moving bed bioreactor), 586 ± 284 gTAN m^{-3} day^{-1} (floating bead filter), and 667 ± 344 gTAN m^{-3} day^{-1} (fluidized sand filter) (Guerdat *et al*., 2010).

Furthermore, the activity of the heterotrophic bacterial population and the nitrification efficiency of a submerged biological filter were studied, for an influent TAN concentration of 2 mg L^{-1} and varying C/N ratios. The filter was filled with a pre-colonized packing media (Biogrog). The TAN removal rate was found to be 30% lower at a C/N ratio of 0.5 than at a C/N ratio of 0. For higher C/N ratios, the reduction in nitrification efficiency was 50% (Michaud *et al.*, 2006).

Biofiltration by seaweed

The efficacy of two seaweed species (*Undaria luctua* and *U. pinnatifida* Suringar) were compared in assimilating nitrogenous wastes, produced by blackfoot abalone (*Haliotis iris*), to biofilm filtration in a recirculating marine aquaculture. The filter used biofilm media comprised of Amiracle Bioballs (Amiracle). Experiments were performed in triplicate and run for 14 days. Although biofilm filtration mantained ammonium at low concentrations (around 0.10 mg L^{-1}), nitrate levels increased linearly over time, reaching 2.30 mg L^{-1}. Seaweeds maintained ammonium at concentrations that were consistently lower (around 0.03 mg L^{-1}) than those observed with biofilm filtration. Moreover, nitrates were undetectable and pH less variable, whilst valuable seaweed biomass, with increases up to 50% was generated. Seaweed filtration thus has the potential to improve the efficiency and productivity of recirculating aquaculture, via enhanced culture conditions and the production of economically valuable biomass (Cahill *et al*., 2010).

The feasibility of using salt-tolerant plants (halophytes) as biofilters to remove nutrients from saline aquaculture wastewater was determined. *Suaeda esteroa*, *Salicornia bigelovii* and *Atriplex barclayana* (Chenopodiaceae), were irrigated to meet evapotranspiration demand and to produce a 0.3 leaching fraction, using aquaculture effluent generated from an intensive tilapia culture system. The effluent salinity was increased with NaCl to make salinity treatments of 0.5, 10, and 35. The plant-soil system removed 98 and 94% of the applied total and inorganic nitrogen, respectively. It removed 99 and 97% of the applied total and soluble reactive phosphorus, respectively. High removal rates occurred despite the high leaching fraction. Salt inhibited ($P < 0.05$) the growth rate, nutrient removal, and volume of water that all three plant species could process. *Suaeda* and *Salicornia*, which are salt marsh species, performed better than *Atriplex* at higher salinities (Brown *et al.*, 1999).

Phytoremediation

The efficiency of two aquatic macrophytes species, *Spirodela polyrrhiza* and *Lemna aequinoctialis* were evaluated in effluents treatment of tilapia *Oreochromis niloticus*. Removal efficiencies of nutrients to 120 h were 75%, 70.3% and 65.8% of $N\text{-}NH_3$; 96, 92 and 75% $N\text{-}NO_2$; 92.5%, 87.0% and 75% $N\text{-}NO_3$; 74.6%, 71.7% and 64.3% NTK; 83.3%, 75.0% and 58.3% TSS; 64.7% (*S. polyrrhiza*), 58.8% (*L. aequinoctialis*) and 33.3% (control) BOD and proximal composition of 95.11% and 92.13% moisture; 30.10% and 33.91% protein; 12.46% and 9.45% fiber; 10.83% and 15.07% ash proportionately. Removal efficiency of nutrient in treatments with macrophytes shows that both plants can be used in treatment of effluents, being a sustainable and economical alternative to aquaculture industry (Galaviz *et al*., 2015).

Systems of natural treatments

Constructed wetland setlands are included in these systems, which have grown in popularity since the early 1980s for treating wastewater (Reed *et al*., 1995). Constructed wetlands have been used to treat acid mine drainage, stormwater runoff, municipal wastewater, industrial wastewater and agricultural runoff from livestock operations. Researchers have shown that wetland systems treatment can remove significant amounts of suspended solids, organic matter, nitrogen, phosphorus, trace elements, and microorganisms contained in wastewater (Kadlec & Knight, 1996).

Furthermore constructed wetlands require very low or zero energy input and, the operation and maintenance costs are much lower compared to conventional treatment systems. In addition to treatment, constructed wetlands are often designed as dual- or multipurpose ecosystems, which may provide other ecosystems services such as flood control, carbon sequestration or wildlife habitat (Vymazal, 2010).

Wetlands

The performance of a constructed wetland (CW) with *Salicornia persica* (Chenopodiaceae) as a biofilter for effluent water drained from a semi-open recirculating mariculture system in southern Israel was studied. The results demonstrate the effectiveness of N, P and total suspended solid (TSS) removal from mariculture effluent by a CW. The CW was exposed to high (3.3 ± 0.26 g N m^{-2} day^{-1}) and low (0.13 ± 0.02 g N m^{-2} day^{-1}) nutrient loads (NL) in two hydraulic regimes, surface flow (SF) and subsurface flow (SSF). The contribution of *Salicornia* as a nitrogen biofilter at high NL was negligible (0.5-0.9% of the total dissolved nitrogen (TDN) compared to the low NL (56-61.4% of the TDN) in both SF and SSF regimes respectively. Using CW systems for effluent treatment requires a relatively extensive area. According to the results, about 10,000 m^2 of CW with *Salicornia* are required to remove nitrogen and TSS produced by 900 kg of 45% crude protein fish feed (11 m^2 kg^{-1} of feed) during one year (Shpigel *et al*., 2013).

A study was conducted to examine the system start-up phenomena and to evaluate system performance in removing inorganic nitrogen and phosphate from aquaculture wastewater under various hydraulic loading rates (1.8-13.5 cm day^{-1}). This test was done in two constructed wetlands, one with free water surface (FWS) and the second with subsurface flow (SSF). Nitrogen removals were excellent, with efficiencies of 86 to 98% for ammonium nitrogen (NH_4-N) and 95 to 98% for total inorganic nitrogen (TIN). The FWS wetland removed most inorganic nitrogen, whereas the SSF wetland removed phosphate at a rate equal to or even greater than the FWS (Ying *et al*., 2002).

Recirculating aquaculture systems (RAS)

RAS technology allows higher intensity of fish farming than other types of systems. Fish are grown in tanks using the most advanced systems, they are indoors in order to control air environment. Water circulates through the system and only a small percentage of water is replaced daily, for instance 10% or less of the volume per day. Temperature, salinity, pH, alkalinity, chemical composition, and oxygen are measured and monitored continuously. Solid waste is filtered and removed from the system, oxygen is incorporated to maintain sufficient concentrations for the fish density in culture, and finally, water is treated in a biofilter for the biological conversion of ammonia nitrogen to nitrate (Timmons *et al*., 2009).

Biofloc technology

Biofloc technology is a technique of enhancing water quality through the addition of extra carbon to the aquaculture system, through an external carbon source or elevated carbon content of the feed. This promoted nitrogen uptake by bacterial growth decreases the ammonium concentration more rapidly than nitrifycation. Inmobilization of ammonium by heterotrophic bacteria occurs much faster because the growth rate and microbial biomass yield per unit substrate of heterotrophs are a factor 10 higher than that of nitrifying bacteria. Suspended growth in ponds consists of phytoplankton, bacteria, aggregates of living and dead particulate organic matter, and grazers of the bacteria (Hargreaves, 2006).

The uptake of microbial flocs (bioflocs) by tilapia was evaluated. Fish were stocked in 1 m^3 tanks filled with water from a limited exchange intensive tilapia producing pond. Tagged ammonium nitrogen ($^{15}NH_4(SO_4)_2$) and starch to ensure incorporation of the ^{15}N into the bioflocs, were added. Fish were held in the tanks for two weeks, not fed during a week period, when the only source of feed was microbial flocs. Floc volume, total suspended solids, as well as total carbon and nitrogen in suspension were monitored. Gross daily uptake of nitrogen as determined using ^{15}N uptake data was 0.25 gN kg^{-1} (1.6 g protein), equivalent to the daily uptake of 6.2 g kg^{-1} of dry bioflocs, 60% of that computed by the simplified mass balance approach. The food contribution of microbial flocs in tested ponds constituted about 50% of fish protein requirement (Avnimelech, 2007).

The effects of the size of biofloc particle when consumed and nitrogen utilization by Pacific white shrimp (*Litopenaeus vannamei*), red tilapia (*Oreochromis niloticus*) and mussel (*Perna viridis*) were investigated. The flocs were sieved grouping them into four different size classes (un-sieved, <48 μm, 48-100 μm, and >100 μm) and subsequently offered to shrimp, red tilapia and mussels. The biofloc class of >100 μm contained the highest levels of protein (27.8%) and lipids (7.5%), whereas the biofloc of <48 μm seemed to be richer in essential amino acids. The total amount of nitrogen that could be derived from biofloc was the highest when the biofloc was larger than 100 μm, *e.g.*, 4.06 gN kg^{-1} shrimp, 3.79 gN kg^{-1} tilapia, and 1.17 g N kg^{-1} mussel, respectively. The trend for the N recovery from the biofloc, however was the highest when the floc was <48 μm. Overall, this study showed that biofloc consumption by shrimp, red tilapia, and mussels occurs irrespective of floc size but that floc size can play an important role in the quality of biofloc in terms of nutritional composition and N retention by each animal (Ekasari *et al.*, 2014).

The zootechnical performance and dietary cost for the marine shrimp (*L. vannamei*) cultured, using different crude protein contents of 24.3, 30.3, 32.9 and 36.7%, in a super intensive biofloc system and a conventional semi-intensive system were compared and evaluated. The study was conducted for 49 days and the experiments showed that *L. vannamei* cultured in semi-intensive and superintensive biofloc systems required approximately 33.0 and 30.0% protein per kg of feed, respectively. These protein levels provided the best performance indices and lower cost of production, demonstrating greater economic viablitity (Jatobá *et al.*, 2014).

CONCLUSIONS

In addition, biodiversity has not been highly preserved and 60% of the global life-supporting ecosystems are now degraded or are on their way to being so, as an impact from different productive activities worlwide. In response, man has the obligation to improve technological innovation, mainly for the development of aquaculture. This literature review reflects a diagnosis on the current status of aquaculture, with analysis in areas of the Mexican Pacific, central and northern Mexico, Gulf of Mexico, and Caribbean Sea. It was found that there are very few species developed through aquaculture production systems, reflecting requirements for further experiments to evolve other kind. These species which are not developed are being overexploited by capture fisheries.

In Mexico, mainly in the Pacific region, the development of aquaculture production systems for the species: abalone, shrimp and clam, have received economic benefits, both for investment in infrastructure, as well as to generate revenue from the marketing of these species. Besides, the success of these production units is directly related to the good management and production practices, sustainable use of resources, and environmentally friendly productive activities.

The sotavento region, in the Gulf of Mexico, is being analized since it has 62% of fish farms engaged in tilapia culture and 38% in fattening and reproduction periods. The environmental impact caused by discharges of effluents from aquaculture production units contain considerable amounts of organic matter, nitrogen and phosphorus, which can degrade even more water quality in receiving bodies. The types of treatments applied to wastewater systems in aquaculture production are poorly implemented to actual production. Among other treatments, some have been performed primarily with commercial biofilters and there has been research conducted on constructed wetlands. It is required further studies to create an effective treatment for this type of effluent. In addition to creating feasible technological innovation to be applied in aquaculture production systems that have a significant impact generating environmental benefits and, in turn, economic type for the productive sector.

Work experiences and future scientific research and technological development have been applied in the development of both marine and freshwater species, typical of the Gulf of Mexico and Caribbean Sea; where through intensive farming systems, semi-intensive and extensive, the water quality in the system is maintained. Currently, an issue has been identified, resulting from the increased volume of effluents in aquaculture production units. The objective of the working group, aims to implement systems for aquaculture effluent treatment using biological processes as an alternative to technological innovation for the Gulf of Mexico, with the full use of natural resources available in the environment. Complying efficiently with the reduction of organic matter, nitrogen and phosphorus contents in aquaculture effluent, so that it can be discharged without causing environmental impacts, both as regards surface as well as ground waters. These models or prototypes could be suitable for other areas of Mexico.

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