ENVIRONMENTAL IMPACT OF FISH FARMING IN FLOATING CAGES IN ISLA ARENA, CAMPECHE

[IMPACTO AMBIENTAL DEL CULTIVO DE PECES EN JAULAS FLOTANTES EN ISLA ARENA, CAMPECHE]

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SUMMARY

Mariculture is the cultivation of marine species of commercial importance. This activity has intensified in recent decades due to the need for food production. The present study evaluated the impact of *Rachycentron canadum* (Cobia) and *Sciaenops ocellatus* (Red Drum) farming in floating cages along the coasts of Campeche, Mexico. The impact of this mariculture system was evaluated through the physicochemical analysis of the sediment from underneath the cages and the analysis of the quality of the water from the farming area. Results showed high concentrations of nitrogen (> 0.5 %) and organic matter (> 80 %), both in the farming area and in the control sites. The concentration of fine sediment showed no spatial or temporal changes. There were no detectable concentrations of nitrites, nitrates, ammonium and phosphates in the water, in a range of 0.1 to 100 mg L^{-1}. The impact caused by this farming system appeared to be non significant, at least in the area of study, due to the constant movement of the water caused by ocean currents which, very likely, carried the waste from the cages to other places.

Key words: Floating cages; nitrogen; organic matter.

RESUMEN

La maricultura es el cultivo de especies marinas de importancia comercial. Esta actividad se ha intensificado en las últimas décadas, debido a la necesidad de producir alimentos. El presente estudio evaluó el impacto del cultivo de *Rachycentron canadum* (cobia) y *Sciaenops ocellatus* (corvina) en jaulas flotantes ubicadas en las costas del estado de Campeche, México. El impacto de este sistema de maricultura se valoró mediante el análisis físico-químico del sedimento localizado bajo las jaulas marinas y de la calidad del agua en la zona de cultivo. Los resultados mostraron altas concentraciones de nitrógeno (> 0.5 %) y materia orgánica (> 80 %), tanto en la zona de cultivo como en los sitios control. La concentración de sedimentos finos no presentó cambios espaciales ni temporales. No se encontraron concentraciones detectables de nitritos, nitratos, amoníaco y fosfatos en el agua, en un rango de 0.1 a 100 mg L^{-1}. El impacto causado por este sistema de cultivo no pareció ser significativo, al menos en el área de estudio, debido al constante movimiento del agua causado por las corrientes marinas, las cuales, muy seguramente, transportaron los desechos generados por las jaulas hacia otros lugares.

Palabras clave: Jaulas flotantes; nitrógeno; materia orgánica.

INTRODUCTION

In the last decades, aquaculture production has diversified, intensified and technologically developed worldwide (Vergara *et al*., 2005). Due to the collapse or endangerment of some continental water systems and to the difficulty of obtaining high-quality water, which is essential for aquaculture, this activity has adapted for using the marine bodies of water. Cage aquaculture is the most widely used technology in mariculture, and makes use of an easily available resource, namely the sea water. During the last 20 years, this type of aquaculture has proliferated in the coastal zones, becoming an important food-generating activity (Ramos *et al*., 2003). In this process, waste is generated and it can have an impact on the environment, particularly in the water column (Effendie *et al*., 2005). Consequently, importance has been given to the effects this activity has on the environment (Fernandes *et al*., 2001).

Because of its nature, fish cage farming maintains high densities of organisms that generate considerable amounts of dissolved and particle-like waste (Islam, 2005). Generally, the waste is discharged into the surrounding environment which acts as a diluting and dispersing agent. Nonetheless, each type of waste can have an impact on the environment, under the shape of nutrients. This results in an enrichment of the environment or in lethal and sublethal indirect toxic effects towards the organisms of the system (Karakassis *et al*., 2000).

The seabed that is close to the fish farming system in floating cages receives a great deposition of feces and non-consumed food (Méndez, 2002). The knowledge of the dynamics of the sediment composition in the aquatic environment is of paramount importance, as it reflects the phenomenon of the transport of the farming system waste that takes place in the water column, and that depends on the conditions of the environment and the season of the year (Pawar *et al*., 2001). The feces and the food leftovers have greater contents of carbon, nitrogen and phosphorus than the natural sediments (Morrisey *et al*., 2000). This causes the seabed underneath these farming systems to have a high content of organic matter and nutrients (Vergara *et al*., 2005).

Therefore, the objective of this study was to evaluate the spatial and temporal differences regarding the organic matter and total nitrogen content, and the granulometric composition of the sediments, as well as the quality of the water in the cultivation area and control sites of a marine fish farming system in floating cages.

MATERIALS AND METHODS

The marine fish farming system had a module of six floating cages joined each other. These cages were placed in front of the community Isla Arena, municipality of Calkiní, Campeche, Mexico (Fig. 1), at 7 km off the coast and 5 m deep into the sea. The coast line was to the east of the cultivation module (Fig. 1). Each cage was 7 x 7 x 3 m in size and maintained a culture density of two organisms m^{-3} in any of the stages of the cultivation process (raising or growing), with the aim to facilitate the handling and to reduce the manipulation of the individuals. In this farming system the species cultivated were *Rachycentron canadum* (Cobia) and *Sciaenops ocellatus* (Red Drum).

Sampling seasons and sites

Three samplings were conducted in the year 2008: the first sampling in January during the windy season, the second sampling in May during the dry season, and the third sampling in August during the rainy season. Sample collection and parameter measurement were carried out during the morning hours in each season. Four transects were drawn from the module to the north-east, north-west, south-east and south-west; two sampling points were marked in each transect: one point at 20 m and the other at 100 m off the module. In addition, another sampling point at the center of the module was considered. A total of nine sampling points were selected in the impact zone, plus two control sites (control), one located at 1 km to the east of the module and the other located at 1 km to the north-west (NE20, NE100, SE20, SE100, NW20, NW100, SW20, SW100, Module, Control 1 [C1] and Control 2 [C2]). In all the sampling points sediment samples were collected. For each sampling point two depths in the water column were considered, one at 0.5 m below the water surface and the other at 0.5 m above the seafloor. A total of 33 sediment and water samples at two depths were collected through scuba diving. The sediment samples were collected using a PVC core sampler with a length of 20 cm and a diameter of 7.5 cm; after that, the samples were placed in plastic bags and kept at 4 to 6 ºC for being carried to the laboratory. The water samples were collected in Van Dorn bottles that were placed in labeled airtight plastic containers kept at 4±1 °C until their analysis in no longer than 12 h after sample collection. The samples were analyzed according to the methods indicated by the AOAC (1995).

Sediment analysis

The granulometric composition and the nitrogen and organic matter content were determined in the sediment samples. The samples were dried at room temperature in flat trays; then, they were introduced in an air flow oven at 60 ºC until obtaining a constant weight (Holme and McIntyre, 1984) 24 h later. For the granulometric analysis, 200 g of dry sediment were weighed and passed through a column of 8, 3.36, 0.84, 0.42, 0.25, 0.149, 0.74 and 0.0625 mm sieves during 15 min, in a mechanic sieve. The sediment retained in each sieve was collected again and weighed to determine the percentage of each portion. The portion that passed through the 0.0625 sieve (fine portion or slime) was used to determine the total nitrogen content by the Kjeldahl method (AOAC, 1995). The organic matter content was determined by loss on ignition (La Manna *et al*., 2007), which measures the sample weight loss after a dry combustion of the organic material. The quality of the water was determined through the amount of nitrites, nitrates, ammonium and phosphates present. The samples were analyzed by triplicate using rapid test kits, approved by the AOAC (1995). An ANOVA test was used to know the differences in the chemical parameters studied among sites, seasons of the year and distance between cages. The Tukey test was used to compare the mean differences of each variable studied ($P < 0.05$).

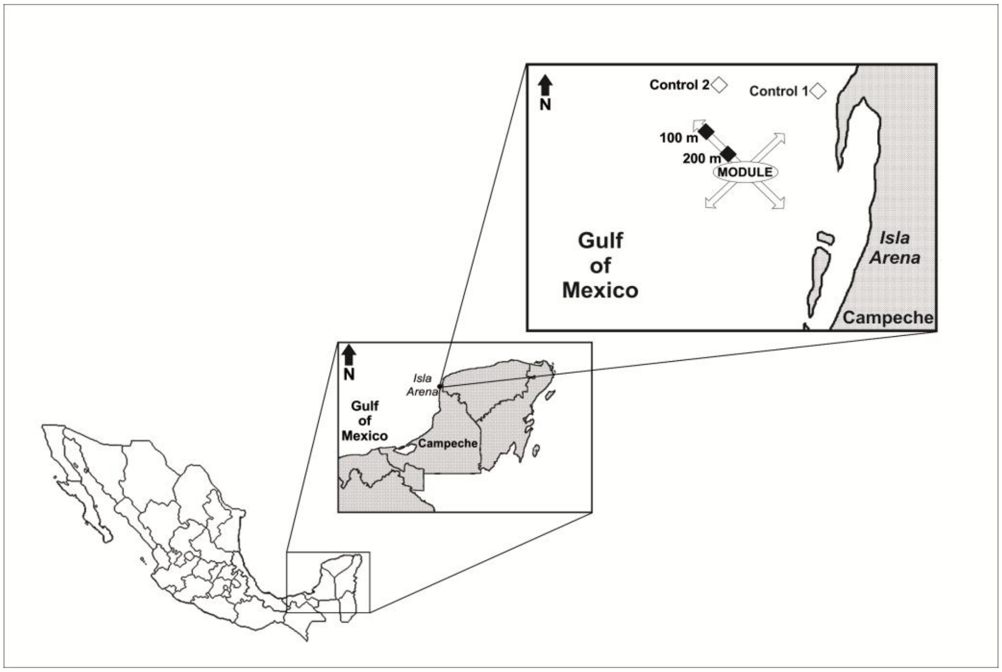

Figure 1. Location of the module of floating cages for the farming of Cobia and Red Drum fish, and distribution of the water and sediment sampling sites, in Campeche, Mexico.

RESULTS AND DISCUSSION

Sediments

The granulometric analysis showed that the fine portion of the sediment had no accumulative behavior over time, although a greater amount was observed during the rainy season. Likewise, a greater amount of fine sediment was observed in the points set up at 100 m off the module. The site underneath the module contained the lowest amount of sediment (Table 1). No significant differences were observed among the impact zone and the control sites, so it could be deduced that the fine particle contents in the sediments were similar in the whole sampled area.

The sand content in the sediments analyzed was greater than 80 % and in some cases greater than 90 %. This was comparable to the observation by Gutiérrez *et al.* (1982), who indicated that the sediments in this area are very slimy, sandy and gravelly. According to Cabrera *et al.* (2004), the resilience of the sedimentary environment is a good indicator of the recovery ability of the environment, which can be measured through the granulometric composition of the sediments. It is, the higher the diameter of the sediment particles, the higher the ability of the environment to recover from the impact caused by waste accumulation.

Table 1. Mean values of fine particle content in sediment samples in the different seasons of the year and sampling sites in a fish farming system with floating cages in Isla Arena, Campeche, Mexico (C1: Control 1; C2: Control 2).

Season of the year (%)			Sampling site (%)				
Windy	Dry	Rainy	Module	20 m	100 m	C1	C2
4.56[ab]	3.88[b]	5.86[a]	2.38[a]	4.15[ab]	5.97[b]	4.92[ab]	4.66[ab]

[a,b]Values with different superscript indicate statistical difference (Tukey, P < 0.05).

The highest nitrogen concentrations were obtained during the windy season, with a mean value of 321 mg g^{-1} (0.32 %). This behavior was probably due to the effect of strong norther winds that blew three days before the sampling, causing the movement or recirculation of the water. Consequently, there was also recirculation of the nutrients present in the sediments, such as nitrogen (Fig. 2). This phenomenon is outstanding in the superficial coastal zones, where the gale-force winds provoke a strong swell, changes in the sea level and intense rainfall, that modify the sedimentary processes in these zones and the chemical composition of the sediment (Gutiérrez *et al*., 1982; Rosales *et al*., 2008).

The site C1 had the highest content of total nitrogen (P = 0.024; 0.40±0.17), different to the values obtained in the site located underneath the module, and to those from the sites located to the north-east, north-west and south-east. This high content of total nitrogen could be the result that the C1 was the nearest point to a human settlement, so it was the site with the highest impact from anthropogenic activities, such as tourism, agriculture, livestock and poultry production. These activities discharge organic wastes into the marine environment, which are transformed into nitrogen compounds that alter the natural cycles of the environment elements. This is more relevant if it is considered that this marine zone is located in the flattest and most superficial continental platform of the entire country (Villalobos, 2004). The differences among seasons of the year and distances of the sampling points are shown in Table 2.

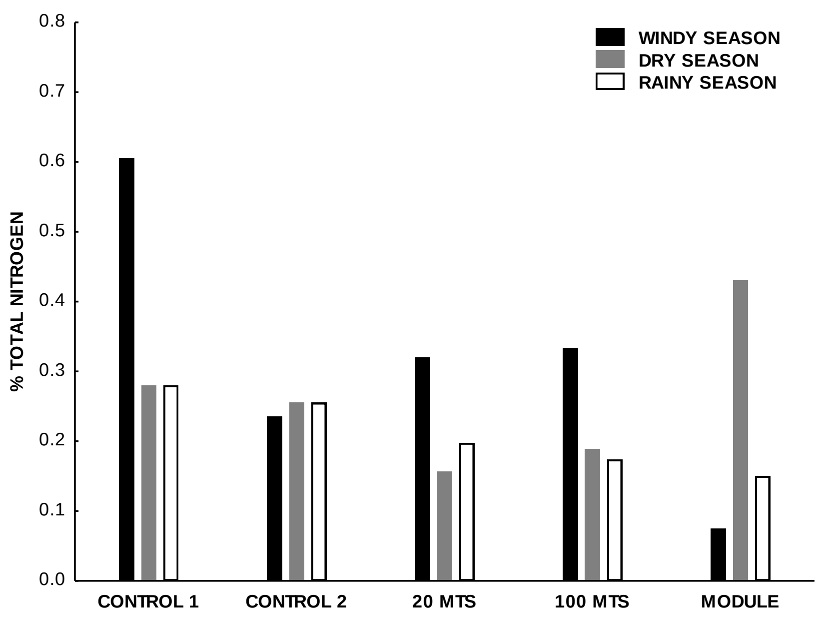

Figure 2. Mean content of nitrogen in the sediment samples during the different seasons of the year and in the sites studied in a fish farming system with floating cages in Campeche, Mexico.

Table 2. Mean values of total nitrogen content in sediment samples in the different seasons of the year and sampling sites in a fish farming system with floating cages in Isla Arena, Campeche, Mexico (C1: Control 1; C2: Control 2).

Season of the year (%)			Sampling sites (%)				
Windy	Dry	Rainy	Module	20 m	100 m	C1	C2
0.30±0.13[a]	0.20±0.09[b]	0.20±0.06[b]	0.20±0.16[a]	0.20±0.1[a]	0.23±0.09[a]	0.40±0.17[b]	0.25±.0[a]

[a,b]Values with different superscript indicate statistical difference (Tukey, P < 0.05).

Of the above mentioned effects caused to the environment by the marine cages, the enrichment of the sediment with nutrients and organic matter, whether dissolved or as particles, is the effect that has been more widely studied (Vergara *et al*., 2005). The installation of farming systems for marine fish causes an accumulation of organic matter made up of food leftovers and organic waste from the organisms that are cultured (Hansen *et al*., 2001). The accumulation of organic matter in the bottom of the ocean, particularly in the zones with a poor current flow, can induce major changes in the chemical composition of the sediments. The changes normally associated with the organic enrichment of the sediment are the reduction in oxygen levels and the subsequent production and release of methane and toxic hydrogen sulphide (Pearson and Rosenberg, 1979). It is estimated that for a zone to be considered as non contaminated, the content of organic matter in the sediment must range from 0.5 to 5 %, whereas the sediments with more than 15 % of organic matter are typical in contaminated zones (Méndez, 2002).

The samples analyzed had a minimum and maximum content of organic matter of 21 and 88 %, respectively, values greater than the 15 % that indicates contamination of the sediments (Fig. 3). The results of the organic matter content indicated that the sampled sites showed contamination due to organic matter.

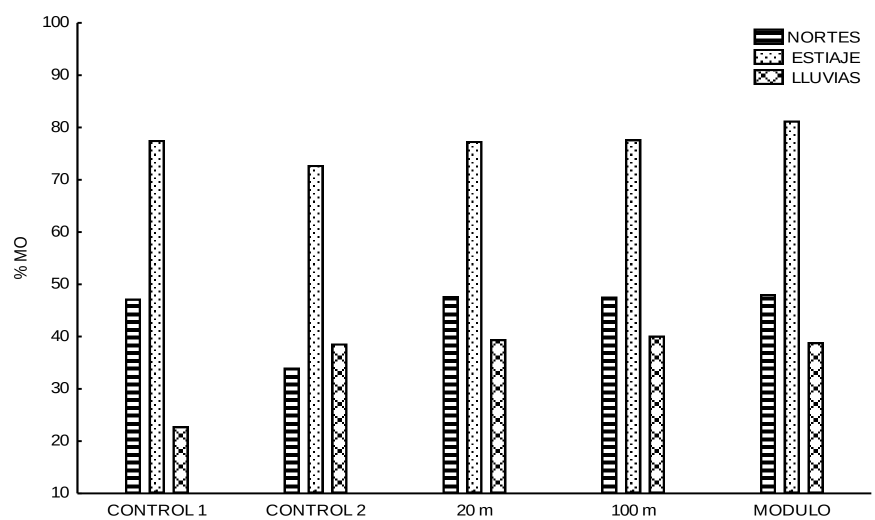

Figure 3. Mean content of organic matter in the sediment samples in the different seasons of the year and in the sites studied in a fish farming system with floating cages in Campeche, Mexico.

The accumulation of organic matter underneath the module (56.1 %) was significantly higher than the content in C1 (48.5 %) (Table 3). Because the two points were located in the same direction respecting the predominant current, it could be deduced that the cage had a great influence on the accumulation of organic matter in this point, since its location very close to the bottom of the ocean prevented the currents from removing the waste. The speed of the current is the best mechanism for the spreading of solid wastes (Hansen *et al*., 2001; Molina and Vergara, 2005; Aguado *et al*., 2006).

Table 3. Mean values of organic matter content in sediment samples in the different seasons of the year and sampling sites in a fish farming system with floating cages in Isla Arena, Campeche, Mexico (C1: Control 1; C2: Control 2).

Season of the year (%)			Sampling sites (%)				
Windy	Dry	Rainy	Module	20 m	100 m	C1	C2
46.4±4[a]	77.4±4[b]	38.07±5[c]	56.2± 20[a]	54.9±2[a]	55.2±17[a]	49.2±24[b]	48.5±19[b]

[a,b]Values with different superscript indicate statistical difference (Tukey, $P < 0.05$).

The results in the present study were different from those reported by Molina and Vergara (2005) in a culture system of *Spaurus aurata* in the Canary Islands, Spain; these authors indicated that the content of organic matter ranged from 5 to 6 % during one year of study, in a culture system located at 18 to 22 m of depth. The results from the windy season were similar to those obtained by Pergent *et al.* (1999), who found 22.4 % of organic matter in the coast of the Mediterranean Sea. The influence the depth has on the accumulation of organic matter can not be questioned, since lower values have been obtained, such as those reported by Grizzle *et al*. (2003) concerning the impact of cage farming at 55 m of depth in Portsmouth, New Hampshire, USA, from year 1997 to 2000, where the organic matter content was lower than 3 % during the study. Aguado *et al.* (2006) evaluated 10 cages at 4.8 km off the coast of San Pedro del Pinatar in Murcia, Spain, at 36 m of depth and with average current speed of 7.85 cm s^{-1}, during one year, and the authors indicated that the organic matter content remained under 4 %. Lytle and Lytle (1982) found organic matter content higher than 10 % near the Mississippi River. Hansen *et al.* (2001), in a salmon culture system, obtained similar organic matter content. Riedel and Bridger (2004) developed a model to predict the impact of fish farming (*Rachycentron canadum*, *Sciaenops ocellatus* and *Dentex dentex*) in the open sea, on the benthos, and concluded that as the depth increases the organic matter content decreases, and culture systems operated at 40 m of depth have 20 % less accumulation of organic matter than those operated at 20 m. Pawar *et al.* (2001) in two culture areas obtained 9.4±2.13 % in the first area and 5.0±1.32 % in the control site; in the second case, the loss on ignition in the culture and control site was 10.3±2 % and 7.5±2.4 %, respectively.

Despite the aforementioned, the contamination due to wastes can not be attributed to the cages, because even though the organic matter content obtained in the two control sites (48.5 %) was slightly lower than that from the culture area (56.1 %), these differences were not statistically significant. Therefore, it can be assumed that there are other factors generating organic matter in the area, such as the organic waste from the abundant vegetation, both aquatic and terrestrial.

Water quality

As for the nutrients in the water column, the values of nitrites, nitrates, ammonium and phosphates in the water column were not detectable in the culture or the control sites, even though one method with a precision of 0.1 mgL^{-1} was used. With a similar method, Effendie *et al.* (2005) reported undetectable values of nitrites, nitrates, ammonium and phosphates in some sampling points. However, using a spectrophotometry method, ammonium concentrations of 0.0024 mgL^{-1} and values lower than 0.004 mg L^{-1} of nitrites and nitrates were registered in floating cages in Puerto Rico. Likewise, maximum values of 0.79 mg L^{-1} of nitrates and nitrites were found in the surface of the water column and 0.84 mg L^{-1} were obtained in the deepest layers in the marine culture area; in addition, phosphates ranged from 0.06 to 0.09 mg L^{-1} and the ammonium content ranged between 0.05 and 0.07 mg L^{-1} (Vergara *et al*., 2005). Molina and Vergara (2005) in marine sediments registered phosphate concentrations ranging from 78.2 to 151.4 mgL^{-1}, from underneath a culture system of *Spaurus aurata* in the Canary Islands, Spain. Likewise, Aguado *et al.* (2006), in a culture of *Spaurus aurata* and *Acanthistius brasilianus* in Murcia, Spain, indicated phosphate values of 79 to 150 mg L^{-1}.

Because the waters in the area of study are considered as oligotrophic, it is, poor in nutrients, and many seagrasses that consume great amounts of nutrients exist in that place, it is not rare that in the present study values lower than 0.1 mg L^{-1} of nitrites, nitrates, ammonium and phosphates were obtained. Therefore, it can be said that the quality of the water did not affect the culture system, since the values were within the ranges indicated by the NOM-001-Semarnat, 1996 (DOF, 1996). The maximum concentrations of nitrites indicated for fish are 0.1 mgL^{-1}. Nitrates usually do not provoke toxicity problems in fish, being the maximum estimated value of 100 mgL^{-1}. Nonetheless, the depth of the area where the floating cages were placed is not the most appropriate site for this type of culture system, and consequently the expansion of this activity could cause a future negative impact on the environment.

CONCLUSION

When considering the different sources of contamination that are present in the area of study, it could be observed that it is negatively impacted by the anthropogenic activities developed outside the culture system. The production system of marine fish that was studied did not impact significantly the composition of the sediments or the quality of the water.

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