Mapping, technical and environmental aspects of shrimp farms in the Acaraú River Estuary, Ceará State, Brazil

Mapeamento, aspectos técnicos e ambientais de fazendas de camarão no Estuário do Rio Acaraú, Ceará, Brasil

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ABSTRACT
Despite the economic importance of shrimp farming, a number of technical problems have been widely reported in the literature. This article focuses on the environmental and socioeconomic impacts of semi-intensive/intensive shrimp farming in the Acaraú river estuary. This estuary has the second largest number of farms in the Ceará state. Currently, the industry has 31 participating farms with a total area devoted to shrimp farming of 1,571.58 ha. In 2013, total production was 7,853.92 tons of shrimp with an average yield of 5.88 t ha^{-1} year^{-1} in an earth pond area of 1,335.49 ha. This industry employs 1,382 people, representing 17.3% of the jobs generated in the two municipalities where the Acaraú river estuary is located. The main environmental impacts of this industry are water pollution and loss of mangroves. However, no changes in water quality parameters were observed during the period 2011-2013, indicating that this estuary has some nutrient processing capacity derived from nurseries, while 159.4 ha of mangrove forests were occupied by In the same period of the establishment of the farms, this estuary presented an increase of 987.41 ha of this landscape unit. The results of this research demonstrate that the Brazilian shrimp industry requires an improvement in management practices to achieve sustainable growth.

Keywords: Shrimp farm, Mangrove, Environmental Impact, Penaeus vannamei.

RESUMO
Apesar da importância econômica da carcinicultura, uma série de problemas técnicos tem sido amplamente relatada na literatura. Este artigo descreve os impactos ambientais e sócio-econômicos da carcinicultura semi-intensiva/intensiva no estuário do rio Acaraú. Este estuário possui o segundo maior número de fazendas no estado do Ceará. Atualmente, a indústria tem 31 fazendas participantes com uma área total dedicada ao cultivo de camarão de 1.571,58 ha. Em 2013, a produção total foi de 7.853,92 toneladas de camarão com uma produtividade média de 5,88 t ha^{-1} ano^{-1} em uma área de viveiros de 1.335,49 ha. Esta indústria emprega 1.382 pessoas, representando 17,3% dos empregos gerados nos dois municípios onde está inserido o estuário do rio Acaraú. Os principais impactos ambientais desta indústria são a poluição da água e perda de manguezais. No entanto, não foi observada nenhuma alteração nos parâmetros de qualidade da água durante o período de 2011-2013, indicando que este estuário tem alguma capacidade de processamento de nutrientes derivados dos viveiros, enquanto que 159,4 ha de florestas de mangue foram ocupados por viveiros de cultivo de camarão, no mesmo período da instalação das fazendas, este estuário apresentou um incremento de 987,41 ha nessa unidade de paisagem. Os resultados desta investigação demonstram que a indústria
da carcinicultura brasileira exige um aprimoramento das práticas de manejo para atingir um crescimento sustentável.

**Palavras chave:** Carcinicultura, Manguezal, Impactos Ambientais, Penaeus vannamei.

1 INTRODUCTION

Despite several sanitary problems, aquaculture production of high commercial value species, such as marine shrimp, should continue to grow in this decade (FAO, 2016). In the Americas, this industry has been relevant in several tropical countries, being Ecuador, Mexico and Brazil the main producers (LIGHTNER, 2011; FAO, 2016). Even with the expansion of the cultivation area, Brazilian production has remained stable in recent years, with levels ranging between 70,000 and 80,000 tons year\(^{-1}\) (DOTE-SÁ et al., 2013; ROCHA et al., 2015).

*Penaeus vannamei* cultivation in northeastern Brazil has been an important income source with high economic yields, particularly for rural communities, including both small and medium producers (MARQUES et al., 2016). However, this activity has faced challenges related to technical and environmental aspects, compromising the sustainability of this agribusiness (QUEIROZ et al., 2013; MARQUES et al., 2016).

Additionally, the rapid development of this activity in an unregulated and uncoordinated way has generated numerous criticisms from traditional communities dependent on natural resources, especially fishermen and farmers (NEILAND et al., 2001; PAUL; RØSKAFT, 2013). The conversion of sensitive coastal environments, including mangroves, into shrimp ponds in various locations, as well as pollution of agricultural land and coastal waters by effluents and pond sludge have been two of the main criticisms of the cultivated shrimp industry (QUEIROZ et al., 2013; FERREIRA; LACERDA, 2016).

In recent years, a considerable expansion of marine shrimp farming has occurred in Ceará State, reaching 10,000 hectares of cultivation area and 50,000 tons of production in year 2015. The growth of this activity has occurred in three main areas that include the estuaries of both Jaguaribe, Acaraú and Coreaú rivers (DOTE-SÁ et al., 2013; ROCHA et al., 2015). Excluding the Jaguaribe river estuary, other estuaries, including the Acaraú river estuary, have been poorly studied (DOTE-SÁ et al., 2013; QUEIROZ et al., 2013; ROCHA et al., 2015; FERREIRA; LACERDA, 2016).

The production area that surrounds the Acaraú river estuary comprises the 2nd shrimp farming area with the highest production volume in the state of Ceará. This area of 428.74 km\(^2\) encompasses territories in the municipalities of Acaraú, Cruz and Itarema, being the 1st geographical area in the world to receive a Denomination of Origin, called "Dark Coast" (Costa Negra), for marine shrimp cultivation. However, there are no studies that report the environmental impacts of shrimp farms in this estuary. The aim of the present study was to present the georeferencing of shrimp farms areas
through the use of satellite images and geoprocessing techniques, as well as to analyze technical and environmental aspects of shrimp farms in the Acaraú river estuary, Ceará, Brazil.

2 MATERIALS AND METHODS

This study was carried out in farms of cultivation of marine shrimp located in the hydrographic basin of the river Acaraú, between the municipalities of Cruz and Itarema. This hydrographic basin is located in the central-north region, occupying about 20% of the territory of the State of Ceará. The study area covers an area of 3,100 km². The estuary of the Acaraú river comprises significant areas of mangrove forests with approximately 240 km², being characterized by having great economic and ecological importance (Figure 1).

In the region covered by the study, all shrimp farming farms were visited to collect technical and operational information. This analysis focused on shrimp production, from post-larvae storage to the harvesting phase (DOTE-SÁ et al., 2013; ROCHA et al., 2015). The methodology was based on field observations, application of interviews and analysis of secondary data (ABREU et al., 2011). The survey was conducted between the years 2011-2013, and included interviews using a semi-structured questionnaire. Respondents were rural landowners or farm managers, traders, processing plant managers, hatchery managers and civil servants. Data analysis was based on field observations, interview transcripts, external sources, including official documents and scientific literature according to Golafshani (2003). Additionally, data were collected regarding both positive and negative aspects of marine shrimp farming. The positive aspects include the creation of formal direct jobs, seasonal jobs, indirect formal jobs, including laboratories and processing plants, foreign exchange inflows, economy diversification, stimulating sectors related to the areas of production and trade, inflows of direct investments and technological transferring. The negative aspects include technical, environmental, economic and social problems.

The methodology applied for shrimp farms identification was based on the satellite images analysis (Landsat 8) with resolution of 15 meters per pixel. Images available on the Google Earth online platform (Quick Bird) with a resolution of 2 meters per pixel were used. Geometric correction was applied to remove distortions from systematic errors present in the images. Then, images were superimposed in layers, using digital aerial photographs edited by the Directory of Hydrography and Navigation (DHN) from Brazilian Navy, in order to characterize the type of land use and occupation of aquaculture farms. These aerial photographs were obtained in the 1960s, when there were no shrimp farms in Brazil. Subsequently, thematic maps were developed from the application of digital image interpretation and geoprocessing techniques available in the software SPRING 4.2 and ArcGIS.
Using image processing and classification results, it was possible to map and research the areas occupied by shrimp cultivation in the Acaraú river estuary.

For sample collection, 12 expeditions were carried out from January 2011 to December 2013, and 6 shrimp farms were visited. During this period, a total of 72 water samples were obtained in the vicinity of the water capture pumping stations, while 144 samples were collected at the effluent discharging points. All water samples were stored in plastic bottles and sent for laboratory analysis according to APHA (1995). The parameters included temperature, salinity, pH, dissolved oxygen (OD), total ammoniac nitrogen (TAN), ammonia, nitrate, nitrite, total phosphorus, chlorophyll a, BOD, turbidity and coliforms. Water quality data were processed through analysis of variance (ANOVA), followed by the Duncan test. A probability level of p <0.05 was considered statistically significant. Values were expressed as the mean + SD.

3 RESULTS

The number *Penaeus vannamei* farms in the Acaraú river estuary included the 31 projects (Table 1). Table 1 shows the division of the farms into three distinct categories: small (<30 ha), with a total of 19 farms corresponding to 20.1% of the total area, medium (between 30 and 100 ha), with a total of 4 farms and 31.2% of the total area, and large (> 100 ha), with a total of 4 farms and 48.7% of the total area. This study revealed that the total area dedicated to shrimp farming was 1,571.6 ha (Figure 2), however the production area (ponds) was 1,335.5 ha (Table 1), while the remaining 236.1 ha refers to other structures such as water supply channels, water discharge channels, dikes, access roads, pumping stations, and etc. Regarding system management, values were very similar between semi-intensive culture, occurring in 51.4% of the farms, and intensive culture, verified in 48.6% of visited farms. Additionally, farms area ranged from 3.9 - 212.3 ha, resulting in an average of 46.2 ha.

Both technical, operational and socio-environmental information on shrimp farms are summarized in Table 2. The nurseries size varied between 0.5 to 47.2 ha, being predominant between 1.5 - 4.7 ha. The average stocking density for shrimp farms in intensive systems was 50 PL m\(^{-2}\) and for semi-intensive system was 20 PL m\(^{-2}\). In the 2011-2013 period, final survival rates remained in the range of 45.4-93.9%. Shrimp farms operate throughout the year with 2.6 to 4.5 year\(^{-1}\) cycle, varying according to the shrimp weight harvested. In year 2013, total production was 7,853.9 tons in a production area of 1,335.5 ha, representing an average productivity of 5.9 tons ha\(^{-1}\) per year. The FCR values varied between 0.98 and 2.07 for different cultivation situations.

Before each production cycle, ponds were emptied and the sludge was removed (both after harvesting and before a new cycle) (Table 2). Depending on the natural conditions in each area, ponds eventually required additional treatment before re-stocking. In the case of soil with acidic pH,
treatment with dolomitic limestone and/or calcium oxide and/or calcium hydroxide was done to neutralize pond’s soil acidity. The typical dosage of these products varied between 1.0 and 3.0 tons ha⁻¹, depending on soil pH. The ponds were then plowed to aerate the soil and facilitate excess organic matter mineralization. Ponds were then disinfected with sodium hypochlorite. After the supply and drainage gates are sealed, ponds are partially filled with water and then fertilized with nitrogen and phosphorus-based products, enabling microalgae to flourish. The water quality before stocking with *P. vannamei* post-larvae (PL) should follow the same management protocol throughout the cultivation.

In this region, this industry generated an average of 1.03 jobs per hectare, both direct formal employment, seasonal employment, indirect formal employment, including hatcheries, growout plants and post-harvest operations (Table 2). Shrimp farms were responsible for generating 371 formal direct jobs and 100 seasonal jobs related to shrimp harvesting. The other secondary activities, including buyers of shrimp and processing industries, generated 778 formal direct jobs. The jobs generated by the fertilizer and feed industries were not considered, as they are not located in the region of the Acaraú river estuary. The local population is the main beneficiary of jobs created. However, qualified jobs are offered to professionals from other regions. In addition, this industry has contributed to the strengthening and diversification of the local economy, increasing the number of jobs in other sectors of industry and commerce.

Currently, the states of São Paulo, Rio de Janeiro, Brasília, Minas Gerais, Bahia, Ceará and Pernambuco are identified as the largest consumers of shrimp in Brazil, with practically 100% of the production destined for the domestic market. Most producers either sell shrimp for processing industries or sell fresh shrimp directly to consumer markets, while a small portion of producers prefer to sell smoked shrimp to the state of Pará. Processed shrimp are shipped overland to supply consumer centers in Brazil. However, there may be some direct sales to other customers, such as supermarket chains, stores, hotels and restaurants. Thus, the shrimp industry has not benefited from the foreign market.

The polygons for the Acaraú river estuary, including salt marshes, mangroves, shrimp farms, diverse land coverings and the Atlantic Ocean were digitized, formatted and overlaid, using digital aerial photographs from the 1960s, before the classification process that resulted in thematic maps with the categories of land use and occupation (Figures 2, 3, 4 and 5). The result obtained with the digitalization of the shrimp farms using images from Landsat 8 and Google Earth (Quick Bird) revealed a total of 31 shrimp farms, covering 1,571.6 ha distributed in the Acaraú river region of influence.
In the Acaraú river, an area of 159.4 ha originally composed by mangroves was found to have been replaced by shrimp cultivation ponds, in the period 1962-2013. On the other hand, in that period there was an expansion of mangrove vegetation from 2,798.3 to 3,785.7 ha, resulting in an increase of 987.4 ha (Figures 3, 4 and 5).

During the time period of the present study, both water temperature, salinity, pH, dissolved oxygen and nitrate did not vary for the samples obtained at all points of water capture nor effluent discharge in any of the analyzes carried out (Table 3). In the case of TAN, ammonia, nitrite, total phosphorus, chlorophyll a and coliforms, the values observed at the water discharge points were significantly higher than those at the pumping station for the three years studied. However, when comparing samples from water collection points and effluent discharge points in the studied period, no significant differences were observed. Therefore, BOD significant differences between the catchment and discharge points were only verified in the years 2012 and 2013, while in the case of turbidity these differences were verified in the years 2011 and 2012. For these two parameters, when water collection stations and discharging points were compared in the period 2011-2013, there was a statistical similarity between the values found.

4 DISCUSSION

In Brazil, there are few reports on the characterization of shrimp farms considering both the technical, economic, social and environmental aspects (DOTE-SÁ et al., 2013; ROCHA et al., 2015; SANTOS et al., 2015). The estuary of the Acaraú river and its area of influence concentrates 31 farms with a production area of 1,335.5 ha the 2nd largest shrimp cultivation area in the state of Ceará, surpassed only by the Jaguaribe river estuary with an area of 2,071.2 ha and larger than the Coreaú river estuary, a productive area of 539.3 ha.

In general, the technical parameters, such as ponds size, stocking density, productivity, etc., and social aspects, such as formal jobs, are very similar among the three main estuaries in the state of Ceará. The technical data presented in the current study are similar to those found by Souza (2011), with discrepancies only in the number of formal jobs per hectare, since in that case results were based on personal communication, having found 2,500 jobs, whereas in the present study, a survey was carried out in all companies regarding number of jobs generated, reaching the value of 1,249 jobs.

Nunes et al. (2005) presented the technical and operational profile of 43 shrimp farms in Ceará State, demonstrating that although there are operational distinctions such as farm size, labor input, and technology, most of the cultivation procedures adopted by shrimp farms are relatively standardized. However, they pointed out the need for the adoption of best management practices (BMP), such as: aspects related to the construction of the farm, evaluation of areas suitable for
cultivation, use of rations appropriated for the environmental conditions of the farms, therapeutic agents, disease management and other routines. Comparing with the data of the present research, it was possible to state that between 2005 and 2012 the technical parameters did not change a fact that can make the activity vulnerable to the occurrence of new disease outbreaks.

The commercial practices and consumer markets of the shrimp farms in the Acaraú river estuary are similar to those observed in other regions from Ceará State, mainly prevailing the fresh shrimp trade with a smaller portion being destined for industrialization (DOTE-SÁ et al., 2013; ROCHA et al., 2015; SOUZA, 2011).

The worldwide mangroves destruction is a cause of concern as they provide relevant services, including raw materials, food, coastal protection, erosion control, water purification, fisheries maintenance and carbon sequestration, and are also a source of tourism, education and research (BARBIER et al., 2011).

In several Asian countries, the expansion of shrimp farming in recent decades has dramatically changed the coastal landscape, in particular by converting mangrove forests into shrimp farming ponds (BOURNAZEL et al., 2015; PAUL; RØSKAFT, 2013). In Brazil, conversions from mangroves to aquaculture, industrial and urban development activities, among others, have caused the suppression of 50,000 ha of mangroves (this figure represents 4% of the country's mangrove) in the last three decades alone (FERREIRA; LACERDA, 2016).

The states of Ceará and Rio Grande do Norte are the main shrimp producers in Brazil (GODOY; LACERDA, 2015; NUNES; ROCHA, 2015). Although only 3% of the Brazilian mangrove area is in these two northeastern states, the forest loss, although relatively small in absolute terms, is proportionally more relevant than in other regions, representing up to 10% of the mangrove, at least twice or three times greater than the country's deforested area (MAIA et al., 2006).

In the present study, there was a similar suppression in percentage terms (10.1%) for the Acaraú river estuary, with a total of 159.4 ha of mangrove area in 1,571.6 ha occupied by shrimp farms. However, even with this suppression, there was an expansion of the mangrove vegetation area by around 0.7% per year, resulting in an increase of 987.4 ha in the period 1962-2012. This rate (10.1%) can be considered high, when compared with other studied estuaries, as in the case of Coreaú river, without suppression, or Jaguaribe river, with a rate of 0.15% (DOTE-SÁ et al., 2013; ROCHA et al., 2015). On the other hand, Tenório et al. (2015), mapping shrimp farms in the Amazon region, found that shrimp farms occupy an area of approximately 0.8 km², 70.6% of which were located in mangrove areas.

It is worth mentioning that the oldest shrimp farms in the Northeast of Brazil, using credit lines from the Superintendence for the Development of the Northeast - (SUDENE) that encouraged
the expansion of the activity, proceeded, in a guided way, the suppression of mangrove vegetation for the implantation of shrimp ponds. Additionally, the first developments occupied former salt flats that were installed on the margins of the estuaries, often occupying mangrove areas (personal communication).

It is known that the continuous effluent release from water changes or harvesting operations can contribute to environmental pollution (ANH et al., 2010). For the studied period, it was found that the parameters of environmental pollution, such as TAN, ammonia, nitrite, total phosphorus, chlorophyll a, turbidity and coliforms, were higher at the effluent discharge points than at the water capture points, indicating a trend of eutrophication in the Acaraú river estuary. In Brazil, to minimize this problem some farms have adapted treatment and reuse of effluents, through the installation of sedimentation basins, and reducing the amounts of sedimented phytoplankton during cultivation, through the use of probiotics (ABREU et al., 2011; MARQUES et al., 2016; ROCHA et al., 2015).

On the other hand, none of the water parameters studied, either at the water collection points or at the effluent discharge points, suffered any type of increase in the three years sampling period, demonstrating that the Acaraú river estuary, therefore, has a probable capacity to assimilate or transform nutrients derived from periodic effluent inputs from shrimp ponds. Another pertinent point is the potential for diluting the volume of effluents discharged by the production units in relation to the volume of water circulating daily in the estuaries due to the influence of the tides and the flow of rainwater. The assimilation hypothesis has not been examined, but it is likely that the process will occur through the mineralization of nutrients, dissipation and dilution through the tides, given that there are other sources of pollution in the estuary, such as, raw sewage discharge from all municipalities located in the Acaraú river hydrographic basin. The reduced time scale does not allow an accurate statement, however, several authors have reported the capacity of assimilation of mangroves into effluents from shrimp ponds (CHOWDHURY et al., 2011; DOTE-SÁ et al., 2013; ROCHA et al., 2015; TROTT; ALONGI, 2000).

5 CONCLUSIONS

This work evaluated technical, economic, social and environmental aspects of shrimp cultivation in the Acaraú river estuary, Ceará, Brazil. These aspects are very important for determining the parameters that will lead to the sustainable development of this industry. In addition, the success of shrimp farming depends on public regulatory policies, a healthy environment and technological advancement. In the Acaraú river estuary, shrimp farm industry is dominated by semi-intensive and intensive cultivation systems, with an average production of 3.45 - 6.25 t ha⁻¹ year⁻¹. In this estuary, shrimp farming has promoted an increase in rural employment, strengthening the local
economy, reducing poverty and improved food security. Due to failures in the international market and high production costs, in recent years most of the shrimp grown in Brazil has been sold domestically. Finally, although some literature reports negative effects of shrimp farming on the environment, the results presented indicate that although some shrimp farms were built in mangrove areas (159.4 ha), it was possible to identify an increase of 987.41 ha in the area of this important landscape unit, also noting that the implementation of shrimp farming was not able to cause significant pollution in the waters of the estuary in question. However, it is important to state that the environmental monitoring period was relatively short and additional studies should continue to monitor environmental variables for longer periods.

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Figure 1 Study Area: Northeast Brazil, highlighting the scope of production areas of the estuary of the Acaraú river, in the municipality of Acaraú (A) and Itarema (B), both in the state of Ceará
Table 1 Characteristics of the shrimp farms by size operation

| Production system | Small   | Medium | Large    | Total   |
|-------------------|---------|--------|----------|---------|
|                   | Number of companies | Area (ha) | Number of companies | Area (ha) | Number of companies | Area (ha) | Number of companies | Area (ha) |
| Semi-intensive    | 8       | 109.38 | 4        | 199.67  | 2       | 377.85  | 14       | 686.90    |
| Intensive         | 11      | 159.32 | 4        | 216.79  | 2       | 272.48  | 17       | 648.59    |
| Total             | 19      | 68.70  | 8        | 416.46  | 4       | 650.33  | 31       | 1,335.49  |

Table 2 Characteristics of the different types of shrimp aquaculture practices

| Characteristics          | Semi-intensive | Intensive   |
|--------------------------|----------------|-------------|
| Pond size (ha)           | 0.5 – 47.2     | 0.9 – 3.7   |
| Stocking density (PL m⁻²)| 13 – 25        | 26 – 80     |
| Survival rate (%)        | 57.2 – 93.9    | 45.4 – 80.6 |

Figure 1 B
| Parameter                     | Value       | Value       |
|------------------------------|-------------|-------------|
| Water exchange (%)           | 0 - 5       | 10 – 25     |
| Aeration (HP ha⁻¹)           | 0 - 2       | 5 – 10      |
| Yield (ton ha⁻¹ yr⁻¹)        | 4.05        | 7.82        |
| Number of crops yr⁻¹         | 3.4 – 4.5   | 2.6 – 3.2   |
| Production (ton yr⁻¹)        | 2,781.95    | 5,071.97    |
| Fertilizers used (ton ha⁻¹ yr⁻¹) | Urea < 0.25, TSP < 0.03 | Urea < 0.50, TSP < 0.10 |
| Feed consumption (ton yr⁻¹)  | 3,324.4     | 8,419.5     |
| Feed used                    | Natural and pelleted feed | Pelleted feed |
| Protein feed (%)             | 40 – 30     | 40 – 35     |
| FCR                          | 0.98 – 1.41 | 1.25 – 2.07 |
| Chemicals used               | No          | No or Little|
| Direct formal jobs (persons ha⁻¹) | 0.78       | 0.82        |
| Direct seasonal jobs (persons ha⁻¹)* | 0.06       |             |
| Indirect jobs (persons ha⁻¹)* | 0.10        |             |
| Disease problems             | Rare (IMNV and IHHNV) | Rare (IMNV and IHHNV) |
| Operational costs            | Moderate to high | Moderate to high |
| Environmental impact         | Relatively little | Relatively little |
| Social implications          | Moderate to high | Moderate to high |
| Economic proliferation       | Commercial   | Commercial   |
| Sustainability concerns      | Moderate to low | Moderate to low |

*The number of jobs was calculated for the total area of shrimp farming activities (1,571.94 ha)
Figure 2 Thematic map of coastal wetland distribution in Acaraú river estuary in the municipality of Acaraú (A) and Itarema (B). Land cover categories obtained by digitization and by means of a supervised classification for Landsat Geocover of 1999-2000, CBERS of 2009-2010 and Google Earth images.
Figure 3 Thematic maps and area estimations of coastal wetland distribution in the Acaraú river estuary in the municipality of Acaraú (A) and Itarema (B). Land cover categories obtained by digitization and by means of a supervised classification for aerial photographs of 1960, Landsat Geocover of 1999-2000, CBERS of 2009-2010 and Google Earth images.
Figure 4 Thematic maps and area estimations of coastal wetland distribution in the Acaraú river estuary in the municipality of Acaraú (A) and Itarema (B). Land cover categories obtained by digitization and by means of a supervised classification for aerial photographs of 1960, Landsat Geocover of 1999-2000, CBERS of 2009-2010 and Google Earth images.
Figure 5 Thematic maps and area estimations of coastal wetland distribution in the Acaraú river estuary in the municipality of Acaraú (A) and Itarema (B). Land cover categories obtained by digitization and by means of a supervised classification for aerial photographs of 1960, Landsat Geocover of 1999-2000, CBERS of 2009-2010 and Google Earth images.
Table 3 Characteristics of the influent and effluent from shrimp ponds in the Acaraú river estuary

| Parameter       | Unit     | 2011                      | 2012                      | 2013                      | Standard
|-----------------|----------|---------------------------|---------------------------|---------------------------|-----------|
|                 |          | Influent (min - max)      | Influent (min - max)      | Influent (min - max)      | Effluent (min - max)  | Effluent (min - max)  |
| Temperature     | °C       | 27.9 (23.7 - 29.8)        | 26.7 (23.7 - 30.8)        | 28.6 (27.6 - 30.0)        | 29.8 (27.1 - 32.2)   | 28.7 (28.2 - 31.0)   | 28.6 (25.1 - 31.1)   | n.a.       |
| Salinity        | ppt      | 24.5 (10.0 - 35.0)        | 27.0 (10.0 - 40.0)        | 32.0 (21.0 - 44.0)        | 49.5 (35.0 - 64.0)   | 35.0 (10.5 - 50.0)   | 38.7 (14.0 - 52.0)   | 0.5 - 30.0 |
| Ph              |          | 7.9 (6.9 - 8.4)           | 8.1 (7.7 - 8.8)           | 7.9 (6.3 - 8.8)           | 7.9 (6.9 - 9.1)      | 7.8 (6.9 - 8.9)      | 7.9 (7.8 - 8.4)      | 6.0 - 9.0   |
| DO              | mgL⁻¹    | 5.3 (3.4 - 6.7)*          | 7.6 (5.9 - 9.5)*          | 5.7 (5.4 - 6.4)           | 4.8 (2.0 - 8.2)      | 5.8 (3.9-6.2)*       | 8.7 (5.9 - 10.8)*   | > 4.0      |
| TAN             | mgL⁻¹    | 0.75 (0.01 - 1.35)        | 1.49 (0.08 - 2.55)*       | 0.30 (0.02 - 2.15)        | 1.55 (0.12 - 2.87)*  | 0.67 (0.09 - 1.77)   | 1.62 (0.48 - 2.07)*  | ≤ 0.40     |
| Ammonia         | mgL⁻¹    | 0.02 (0.00 - 0.07)        | 0.10 (0.00 - 0.18)*       | 0.01 (0.00 - 0.08)        | 0.09 (0.01 - 0.23)*  | 0.01 (0.00 - 0.06)   | 0.11 (0.01 - 0.22)*  | n.a.       |
| Nitrate         | mgL⁻¹    | 0.61 (0.10 - 0.73)        | 0.76 (0.12 - 1.60)        | 0.55 (0.10 - 1.90)        | 1.19 (0.10 - 2.00)*  | 0.55 (0.20 - 1.10)   | 0.60 (0.30 - 1.00)   | ≤ 0.40     |
| Nitrite         | mgL⁻¹    | 0.02 (0.00 - 0.08)        | 0.11 (0.07 - 0.37)*       | 0.03 (0.00 - 0.30)        | 0.10 (0.00 - 0.18)*  | 0.02 (0.00 - 0.20)   | 0.09 (0.01 - 0.25)*  | ≤ 0.07     |
| Total phosphorus| mgL⁻¹    | 0.12 (0.02 - 0.22)        | 0.14 (0.06 - 0.21)        | 0.11 (0.02 - 0.22)        | 0.19 (0.05 - 0.38)*  | 0.11 (0.05 - 0.25)   | 0.18 (0.10 - 0.26)*  | ≤ 0.12     |
| Chlorophylla    | µgL⁻¹    | 4.7 (1.0 - 10.0)          | 18.3 (3.0 - 37.0)*        | 3.9 (1.1 - 8.2)           | 12.7 (2.3 - 22.0)*   | 4.0 (1.2 - 8.2)      | 10.5 (4.0-12.2)*     | ≤ 30.0     |
| BOD             | mgL⁻¹    | 5.1 (1.0 - 13.6)          | 6.7 (2.1 - 12.5)          | 4.6 (2.4 - 7.5)           | 11.9 (5.4 - 21.8)*   | 6.6 (1.0 - 20.5)     | 12.2 (6.1 - 17.5)*   | n.a.       |
| Turbidity       | NTU      | 11.6 (10.0 - 13.0)        | 23.2 (11.0 - 42.0)*       | 9.0 (4.0 - 12.0)          | 11.6 (9.0 - 14.0)    | 10.2 (4.0 - 31.0)    | 18.8 (9.0-37.0)*     | n.a.       |
| Coliforms       | MPN100 mL⁻¹ | 120.0 (0.0 - 300.0)     | 200.5 (20.0-320.0)*       | 112.0 (10.0-220.0)*       | 190.0 (20.0-380.0)*  | 110.0 (20.0-240.0)*  | 210.0 (20.0-1200.0)* | ≤ 2500.0   |

n.a. = Not Available; ¹CONAMA (Brazilian National Environment Council) Resolution number 357 of March 17, 2005 (Brazilian water quality standard for industrial effluents discharged into brackish water). Asterisks denote significant differences between Influent and effluent for each year studied.
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