Ocean & Coastal Management 73 (2013) 54–62

Contents lists available at SciVerse ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Shrimp aquaculture in the federal state of Ceará, 1970–2012: Trends after mangrove forest privatization in Brazil

L. Queiroz [a,*], S. Rossi [a], J. Meireles [b], C. Coelho [c]

[a] Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, Edifici Cn Campus UAB, Cerdanyola del Vallés, Barcelona 08193, Spain
[b] Programa de Posgrado em Geografía de la UFC, Universidade Federal do Ceará, Fortaleza, Brazil
[c] Instituto de Ciências Biológicas, da Universidade de Pernambuco, Pernambuco, Brazil

ARTICLE INFO

Article history:
Available online 10 December 2012

ABSTRACT

During the last 40 years, industrial shrimp farming in Brazil has experienced intense development. The first shrimp culture experiments were carried out at the beginning of the 1970s, but due to technical problems and a lack of exact knowledge they were not very successful. At the end of the 1990s, the activity expanded rapidly and shrimp farming became a relevant export industry, due to government assistance, public-bank financing, university technical collaboration and legislative permissiveness. The vertiginous growth of the industry has been accompanied by a profound transformation of natural resources, causing the degradation of the mangrove ecosystem. The objective of this study is to conduct an integral and in-depth analysis of the evolution of the industrial shrimp farming in Brazil, based on a review of the national political and economic context of the aquaculture activity, and also an evaluation of the environmental impacts of shrimp farming in the watershed of the Jaguaribe River, Ceará (NE Brazil). This analysis begins with the initiation of intensive large-scale farming for export, taking into account the synthesis of environmental processes to analyse the socio-environmental impacts.

We studied the areas used for the construction of shrimp farms, located in coastal and estuarine systems and with tidal connections, linking the transformation of the system with the, geo-environmental evolution of the impacted zones, mainly the mangrove ecosystem. The final objective of this work is to propose an integral model of management for the appropriate use of mangroves in Brazil and other systems with analogous problems.

1. Introduction

Aquaculture has been promoted to reach strong economic growth based on food export alleviating poverty in developing countries while decreasing the pressure on wild marine populations (the so-called "*blue revolution*," [Bardach, 1997; Stonich and Bailey, 2000; Costa-Pierce, 2002]). The "*blue revolution*" (Austin, 1993; Naylor et al., 2000) began to develop intensively in tropical zones of Asia, Latin America and, more recently, Africa. The "*blue revolution*", previously practiced in an extensive form in Asia for nearly 4000 years (Arana, 1999), has been transformed, with strong political and economic support, into a more intensive form adopted by the world agro-industrial food systems. Following the same logic of other animal production systems, aquaculture has been converted into an activity that is highly dependent on the globalised industrial market.

World aquaculture production has grown substantially in the last ten years, reaching 52.5 million tonnes in 2008, compared with the more than 2.5 million tonnes in 1970 (FAO, 2010). Production grew from 0.7 kilos/capita/year in 1970 to more than 7.8 kilos/capita/year in 2008, growing on average 6.6%/year. One of the stronger points of the *blue revolution* is shrimp aquaculture. From the 1990s to the mid-2000s, the shrimp farming industry has grown each year between 3 and 54% relative to the previous year (FAO, 2010). Peneids (shrimp and prawns) aquaculture alone has comprised 73.3% of the world crustacean aquaculture production (FAO, 2010). Countries such as Myanmar transformed this industry from one tonne/year (1990) to more than 30,000 tonnes/year (2004), while others such as China have increased their productivity from 185,000 tonnes to almost a million in the same period (Rivera-Ferre, 2009). Almost 99% of shrimp production comes from developing countries, but the majority is exported to Europe, Japan and USA (Paez-Osuna, 2001).

According to recent estimates, 1 to 1.5 million hectares of coastal areas were converted to shrimp farms, mainly in China, Thailand, India, Indonesia, the Philippines, Malaysia, Brazil, Ecuador, Mexico,

* Corresponding author.
E-mail address: luvitales@gmail.com (L. Queiroz).

0964-5691/$ – see front matter
http://dx.doi.org/10.1016/j.ocecoaman.2012.11.009

Honduras, Panama and Nicaragua (Senarath and Visvanathan, 2001). Shrimp monoculture has been carried out in these countries without regulations or laws in many cases, and its steep growth in recent years has been accompanied by an ecological footprint on natural resources and landscape, especially in mangrove ecosystems (Paez-Osuna, 2001).

The first shrimp cultivation experiments in Brazil were carried out in the early 1970's. It was only towards the end of the 1990's, however, that rapid expansion of the activity took place and it became a relevant export industry, reaching its highest level of production in 2004 (ABCC, 2004). In order to reach this level of development, shrimp aquaculture occupied an area of more than 15,000 ha, in contrast to 4320 ha in 1998, a growth rate higher than 300% (1998–2010) (Fig. 1). Even more dramatic was the growth in production, with a rate of 2400% during the same period. Brazil became the largest producer in Latin America and occupied sixth place in global production (ABCC, 2004).

In 2004 the Associação Brasileira de Criadores de Camarão (ABCC) envisioned continuity in this trend in aquaculture growth, predicting area coverage of 30,000 ha by 2007. However, with the decrease in the value of the dollar and, toward the end of 2003, the spread of the Infectious Myonecrosis Virus, IMNV, the activity stagnated (ABCC, 2005). Following successive decreases in shrimp aquaculture production in 2003 and 2004, the shrimp industry began to fall into steep decline. In the federal state of Ceará, the accumulated decrease of exports was 65%. Faced with export difficulties, the sector stated that in 2010 practically all production would be absorbed by the domestic market, and this increase in domestic demand continued during the following years (ABCC, 2010). The data from 2010 (Fig. 1) was estimated by the ABCC and may be overvalued.

Behind the numbers and high shrimp-production rates for export, lies a context of conversion of extensive coastal areas (fragile and fundamental environmental systems like wetlands and mangroves), into production zones (shrimp farms), generating social, economic and environmental impacts (Barbier and Strand, 1998; Ronnback, 1999; Polidoro et al., 2010). The extension and magnitude of environmental impacts vary according to the geographic and environmental conditions of each place, but a strong degradation and transformation of habitats has been demonstrated. These habitats have a very important role in the regenerative capacity of natural environments, water consumption, generation and treatment of effluents, and other environmental, social and economic characteristics (Braaten and Flaherty, 2001; Huitric et al., 2002; Alonso-Perez et al., 2003).

Mangroves are a rich, diverse and complex ecosystem formed at the interface between terrestrial, estuarine, and marine systems near the coastal zone of 123 countries in tropical and subtropical regions of the planet (Spalding et al., 2010). This biotope is responsible for several ecosystem services which include, among others, protection against floods and cyclones, control of nutrients, processing of organic material, control of sedimentation, biodiversity environments, and above all, temporary and permanent nursery grounds for a large quantity of fishery species (Spalding

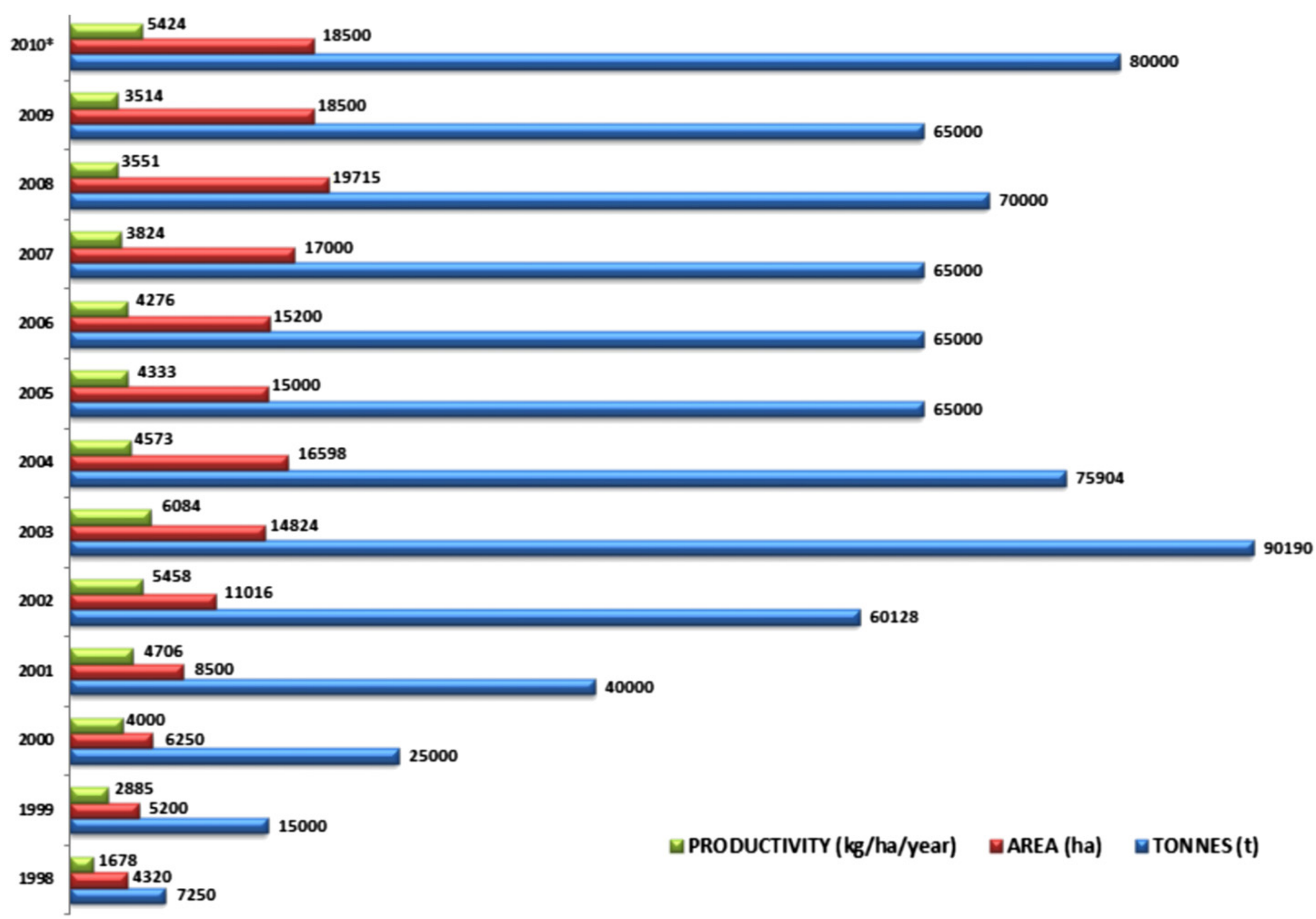

Fig. 1. Shrimp production in Brazil 1998–2010 (ABCC, 2010).

et al., 2010). The last point has been widely demonstrated (Laegdsgaard and Johnson, 2001; Nagelkerke et al., 2002), being crucial in order to understand the value of the artisanal and industrial fishing that can occur in mangrove areas (Aburto-Oropeza et al., 2008). Adding to these services, the ability to bind large carbon from the atmosphere in its aboveground biomass in the sediment is considered one of the largest carbon sink on the planet.

Current estimates of global mangrove area are about 150,000 km^2 (Spalding et al., 2010). Around 35,600 km^2 (about 23% of mangroves and wetlands) were lost between 1980 and 2005 due to the growing pressure of urban and industrial development along coastal zones, in combination with climate change and sea level rise (FAO, 2007). 38% of degraded mangrove areas are attributed to industrial shrimp aquaculture, being directly related with decreases in its ecosystem services (Ellison, 2008; Polidoro et al., 2010). Very conservative calculations indicate a 1% loss of mangrove area/year, while other calculations reach up to 8%. It has been shown that 11 of the 70 mangrove species (16%) are in a critical condition and may disappear in less than a decade, especially in the Atlantic and Pacific coastal zones of the Americas (Polidoro et al., 2010). Taking into account this accelerated rate of loss, the predictions of some authors foresee a disappearance of all mangrove species within 100 years (Valiela et al., 2001; Alongi, 2002).

Although research has been carried out on the impact of shrimp farming on mangroves, an easy and manageable tool is required to make long-time series which help to quantify the real impact of intensive aquaculture. This is the first work in which there is a long-time series of shrimp farming development through satellite data in Ceará, Brazil, from 1970 to 2011. The study area is the watershed of the Jaguaribe River (Fig. 2). The watershed area is 72,645 km^2 (occupying 50% of the state area). Its area contains 80 municipalities with one-third of the population of Ceará (IBGE, 2010). The economic activities carried out throughout the Jaguaribe watershed range from small family farming, traditional fishing, and garbage dumps, to industrial shrimp farming (Souza Filho et al., 2003).

We applied two different approaches: 1. Reconstruction of the national political and economic context of the shrimp monoculture intensification and 2. Characterisation of the environmental impacts associated with shrimp farming in mangroves of the Jaguaribe River. In the first part, we show the evolution of production in Brazil mainly beginning in 1997, a historic point in the production of shrimp by means of intensive cultures for large-scale export (EMBRAPA, 2004; IBAMA, 2005) by means of official documents and statistics. In the second part we consider the importance of salt flats and their relation with other associated coastal ecosystems by means of correlations with transport and deposition of sediments, oscillations of the tides, fresh water inputs (subterranean, fluvial and pluvial) and seasonality (Meireles et al., 2007).

The work is intended to be a clear example to be applied to other similarly affected areas in which the political context may be different but the result (the degradation of mangrove systems for the intensive shrimp aquaculture) is the same.

2. Methodology

The methodology of the present study is divided in two different parts: 1) An integrated literature/document analysis of the industrial shrimp aquaculture development in Brazil, and 2) Survey of the case study area through the SIG methodology and the implementation of aquaculture and environmental data.

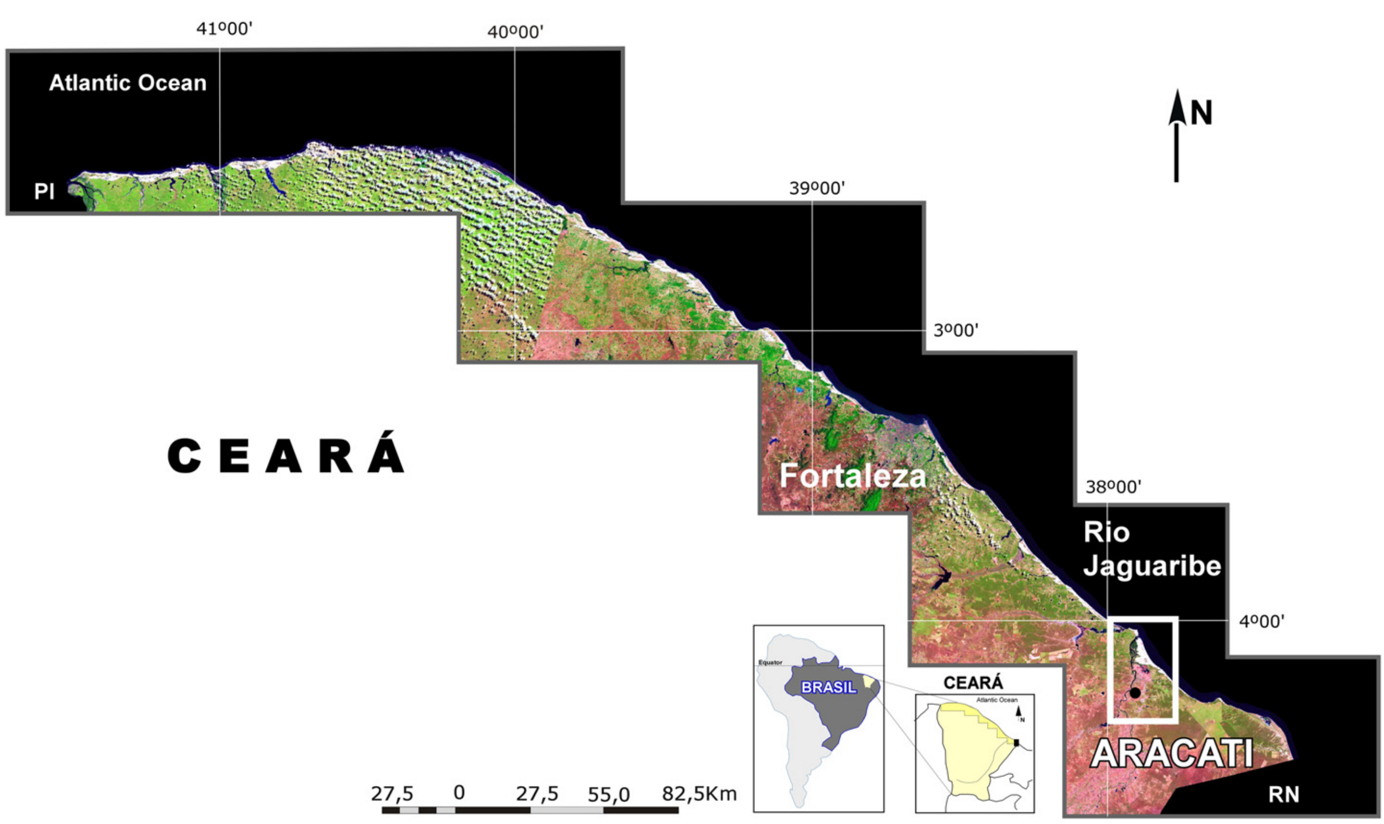

Fig. 2. Area of study. Source: www.embrapa.gov.br.

2.1. Reconstruction of the political and economic context

The literature/document analysis gathers historical information of the shrimp production from the beginning of intensive crops in 1997 up to 2010. To reach this target we made a literature review with the various sources of information: 1. Government: review of the plans and strategies of the federal and state governments for the development of public policies for aquaculture and studies on the social and environmental impacts caused by environmental agencies (EMBRAPA, 2004; IBAMA, 2005) 2. Scientific publications on aquaculture development in Brazil and its social and environmental impacts on coastal communities and traditional territories mainly produced by the universities of Ceará: Universidade Federal do Ceará (UFC), Instituto de Ciencias do Mar (Labomar) and Universidade Estadual do Ceará (UECE) 3. Business (aquaculture production sector): Associação Brasileira de Criadores de Camarão (ABCC)/Associação Cearense de Criadores de Camarão (ACCC) 4. Community/social movement information: the allegations made by the communities involved in the conflict generated by the shrimp aquaculture expansion.

2.2. Survey of the area of shrimp farms in the watershed of the Jaguaribe River, Ceará, NE Brazil

The spatial-temporal evolution of mangroves was analysed using satellite images (Landsat TM5, bands 1–7, colour 5R, 4G and 3B), with 30 m resolution. Aquaculture activities were detected, and could be easily recognised in the image set, generating the composition of the data base for the characterisation of environmental impacts.

The field data were used for the elaboration of thematic maps (geologic, geomorphic and plant cover) at the Digital and Climatological Cartography and Hydrologic Resources laboratories of the Department of Geography of the Federal University of Ceará (UFC), Brazil. To compose the models and the synthesis of collected data, diagram blocks were elaborated with mapped themes. Environmental impacts were introduced into these models. In order to quantify the impact analysis, the characterisation of the flux of material and energy was elaborated by marking the boundaries of the geo-environmental units in two coastal systems and the characterisation of the sediment transport agents. Based on the observed intervention of shrimp ponds in geo-environmental and eco-dynamic processes, planning and management suggestions were developed for this aquaculture activity in the Brazilian coastal zone.

Areas impacted by shrimp farm production were surveyed in the Jaguribe River estuary. Geo-environmental and eco-dynamic processes were defined in the salt flat sectors and related with the flux of material and energy that make up the structure of the mangrove ecosystem.

3. Results

3.1. Reconstruction of the political and economic context

During the last 42 years, the shrimp farming sector in Brazil has evolved from experimental production on extensive farms of autochthonous species to the creation of an extremely flexible institutional and infrastructural mark, designed to promote rapid expansion of aquaculture with maximum profit. During these years, the shrimp farming industry has developed in four stages.

The first stage began in the 1970s in the state of Rio Grande do Norte, when the country carried out the first experimental cultures. The shrimp aquaculture then became a business in the 1980s, using the exotic species *Panaeus japonicus*. At this time, the sector needed to reach a more economically acceptable production rate and faced the lack of adaptation of *P. japonicus* to low salinities. The aquaculturists changed their plans and started to experiment with native species, such as *Panaeus subtilis*, *Panaeus schmitti*, *Panaeus brasiliensis* y *Panaeuspaulensis* (BRASIL, 2010). Productivity, as well as the profits obtained, continued to be low, which provoked the deactivation and reconversion of the shrimp farms into salt ponds in several regions of NE Brazil because of the difficulty of managing production systems.

The second stage of shrimp farming development in Brazil began when a technological package (optimum aquaculture conditions, life cycles, study of potential diseases, genetic variability, etc.), focused on fostering the industry was introduced. From around 1997–2003, the country had the ideal conditions to obtain accelerated aquaculture growth. In the following years, the mastering of the reproductive cycle and post-larva production technology resulted in self-sufficiency and regularisation of the supply, consolidating the technology in the farms. The country no longer had to depend on the importation of post-larvae, which had been vectors of disease and fraught with irregular supply, resulting in negative performance outcomes (Paiva Rocha, 2011).

The NE of Brazil possesses scientific development as well as ideal edaphoclimatic conditions, both in terms of topographical, hydrological characteristics, for shrimp farming. The university technical collaboration: ideal conditions as extensive areas of estuary, good quality of coastal waters and tropical climate, government assistance, public-bank financing and legislative permissiveness enabled the shrimp farming to grow during this period, introducing the Pacific shrimp in Brazil on a large scale.

In order to reach a high level of biomass growth, shrimp farms bought extensive lands in the Brazilian coastal zone: from 3500 ha of farms installed in 1997 to more than 15,000 ha in 2004, representing an increase of more than 300% (ABCC, 2005). Even more significant was the rise in production, which in 2003 reached 90,190 tonnes, an increase of 2400% in relation to 1997. Of this production, 70% was for export. This period is known as the shrimp farming *"boom"*, driven forward by the increase in the exchange rate of the national currency with the dollar, making the external market more attractive (Meireles et al., 2007; ABCC, 2005).

In 2004 there was a decrease in export production volume. by 19,405 tonnes in the north west zone and, in Rio Grande do Norte, shrimp production in 2003 was 37,473, decreasing to 30,807 tonnes in 2004. At this time, exports decreased by 65% in Ceará. The rates reached their lowest levels in 2006, when national production did not pass the production reached by Rio Grande Norte alone in 2003, with a volume of approximately 34,000 tonnes (Meireles and Vicente da Silva, 2003).

In only three years, exports dropped from US$ 244.5 million in 2003 (with 61,000 tonnes) to US$ 154.4 million in 2006 (37% less). The data demonstrate that the intentions of the shrimp farmers to reach 157,000 tonnes in 2005 with a value of US$ 450 million were badly estimated ABCC). According to the data from the first half of 2005, exports were estimated at US$ 283 million less than predicted by the ABCC.

3.2. Survey of increase in shrimp farm area

According to the survey carried out by the Superintendência Estadual de Meio Ambiente (SEMACE), 245 shrimp farms were identified within the watersheds of the state of Ceará (IBAMA, 2005), occupying an area of 6069.97 ha. The data reported by ABCC in contrast for 2005 were 3804 ha. 84.1% of the those farms had impacts directly related with mangrove loss, such as environmental damage to mangrove fauna and flora and salt flat sectors (Meireles and Vicente da Silva, 2003). The Fig. 3 represents

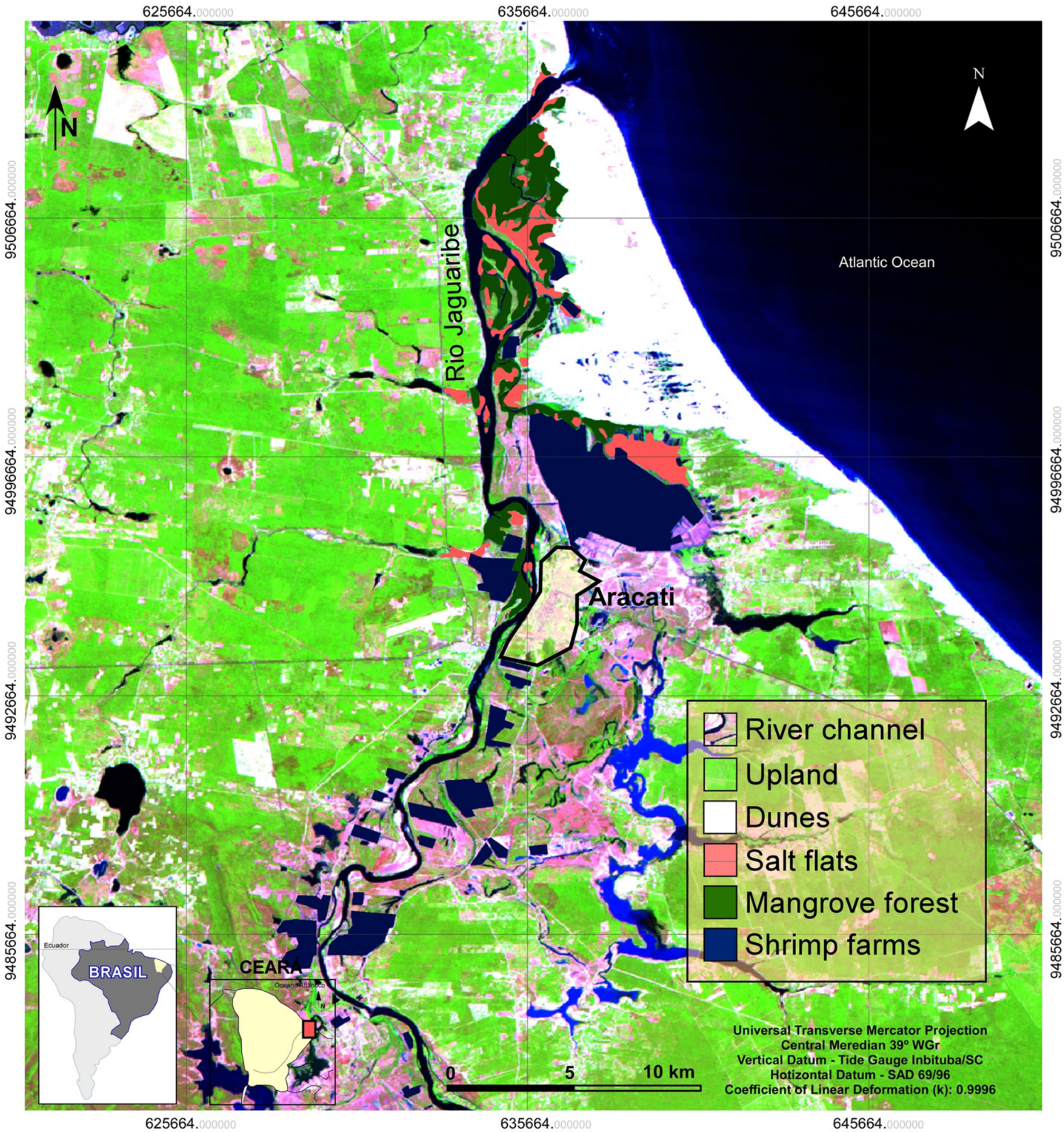

Fig. 3. Estuarine system of the Jaguaribe River and its principle environmental components. (Source: National Institute for Space Research (INPE), satellite image Landsat TM 5, 8 March 2008).

a synthesis of the characteristic geo-environmental units throughout the estuarine system of the Jaguaribe River and how they were occupied by shrimp production units. Also characterised are the impacts related to access roads, larva and post-larva growing ponds, storage and drainage canals, sedimentation ponds, laboratories and tool/material storage.

Of all the farms licenced by the State Superintendent of the Environment (SEMACE), it was verified that 84% had direct impacts on the mangrove ecosystem (mangrove fauna and flora, salt flats); 25.3% cut down carnaubal palm forests and 13.9% occupied areas previously destined for subsistence agriculture. Throughout the watershed there was an increase in the area of shrimp farms from 295 to 1985 ha, with a decrease in mangrove forests in 1999 and a slight increase in area (probably related to the occupation of mangrove in former areas of abandoned farms and salt flat sectors colonised by the forest). Fig. 4 presents the occupation of the

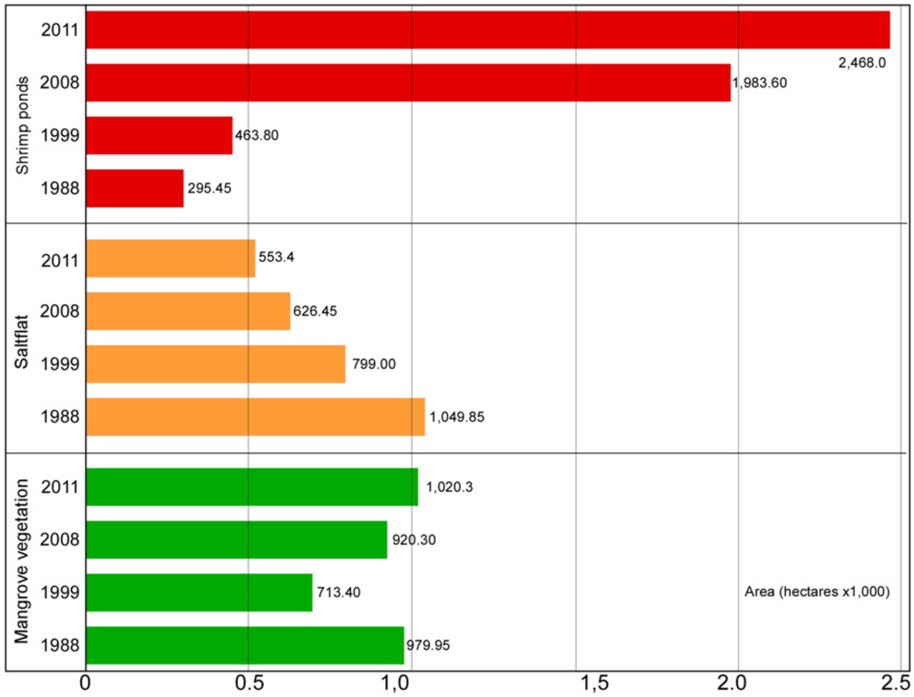

Fig. 4. Occupation of the mangrove ecosystem related with vegetation and salt flats through the period studied (1988–2011).

mangrove ecosystem through the period studied, where there is a significant increase in shrimp farm areas, occupying ecosystem sectors related with vegetation and salt flats.

According to the Superintendência Estadual de Meio Ambiente (SEMACE), 44.2% of the shrimp farms constructed in the Jaguaribe River, interfered directly with the mangrove ecosystem and 63.6% caused serious damage to the riparian forest (carnaubal palms), which is one of the most important ecosystems of NE Brazil primarily for the protection of areas of recharge (IBAMA, 2005). Fig. 5 shows the synthesis of the occupation process, and the relation between the increase in shrimp farms and decrease in vegetation cover and salt flats. These results also demonstrate that the mangrove occupation was related to the substitution of environmental components with extensive aquaculture.

Fig. 6 represents a synthesis of the characteristic geo-environmental units along the estuarine system of the Jaguaribe River and how they were occupied by the shrimp production units. Also characterised were the impacts related to the access roads, larva and post-larval phase tanks, storage and drainage canals, sedimentation ponds, laboratories and tool/material storage. Additionally, the impact on biodiversity caused by the dissemination of exotic species was also identified. The farms do not have efficient security mechanisms to prevent the invasion of the exotic shrimp L. vannamei which is harmful to Brazilian mangroves (Meireles and Queiroz, 2010; Meireles and Tupinambá, 2005). In addition, contaminated effluents directly affect the biology of native species.

According to Fig. 6, the environmental impacts identified in the Rio Jaguaribe caused by shrimp aquaculture were:

1. Geo-environmental and eco-dynamic decharacterization of the mangrove ecosystem by deforestation (mangrove carnaubal palms, etc.);
2. Deforestation of riparian zones associated with the lateral areas of mangrove salt flats;
3. Impermeabilization of soils near urban areas and fishing villages, destroying aquifer recharge areas;
4. Risk of aquifer salinization due to the occupation of extensive recharge areas;
5. Blocking of the tides, preventing access to water (nutrients and seeds) in areas with mangrove vegetation and in salt flat sectors;
6. Hindering the entrance of fresh water originating from the aquifer (water renovation cycle and leaching of salts) in the internal eco-dynamic of the salt flat, and, consequently, for the estuary.
7. Transformation of mangrove vegetation (and salt flats); structural changes (loss of sedimentary material and compaction).
8. Erosion of the shrimp pond slopes (pluvial action and contact with daily tidal oscillations) and destruction of mangrove vegetation and slat flat areas;
9. Direct discharge of effluents in the creeks;
10. Death of vegetation (mangroves, carnaubal forest and caatinga), probably resulting from the infiltration of brackish water and blockage of lateral exchanges with the implantation of polders and infrastructure.

4. Discussion

The technique that we have used to evaluate the changes in the altered area caused by the presence of shrimp farms proves to be adequate for making a good landscape evaluation. It is easy to use and can be combined with shrimp production data, including the downward trends that in this case have been detected in the state of Ceará in recent years.

In the 1990s, intensive shrimp production started to be developed in Ceará. In only 10 years (1998–2008), the activity had already developed in eight municipalities, corresponding to 48% of the entire cultivated area in the state and being responsible for more than 80% of the total shrimp production in that zone of Brazil. Of the 6069.97 ha of shrimp production, the Jaguaribe watershed region was responsible for 3294.88 ha during this period (including shrimp farms in fluvial systems, far from the estuary). In the lower Jaguaribe, the ponds were first installed in the river margins, where

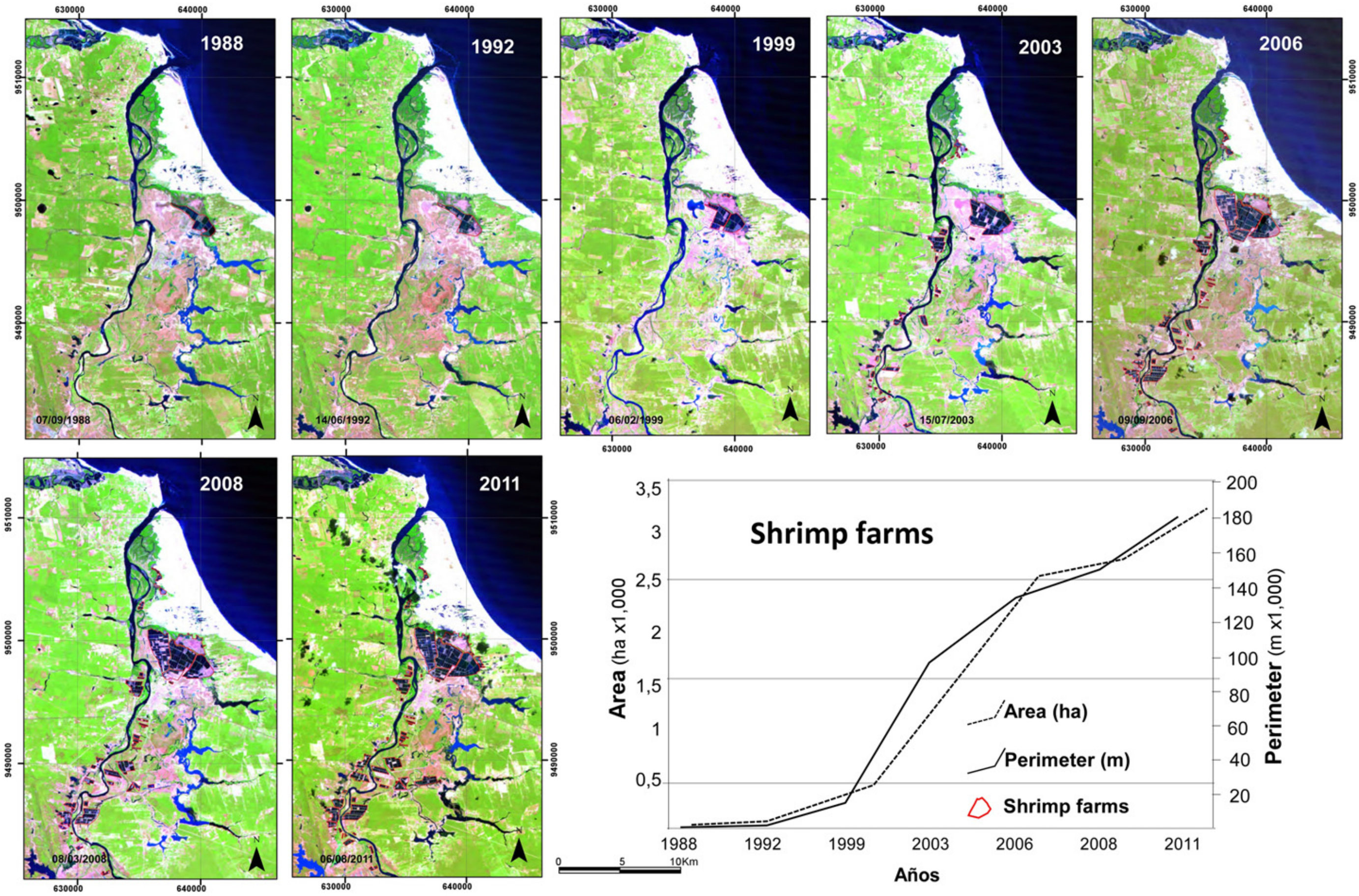

Fig. 5. Evolution of mangrove forests and shrimp farms along the Jaguaribe River estuary (Meireles and Tupinambá, 2005; Meireles and Queiroz, 2010).

salt flats and mangrove trees were located. There was a great *boom* in shrimp production, causing large transformations in the ecological equilibrium in a short period of time (IBAMA, 2005; Meireles and Vicente da Silva, 2003).

Economic activities that follow different programs of development are taking place on the same estuarine system of the Jaguaribe River watershed. Shrimp aquaculture obeys the logic of appropriation of space generating socio-environmental consequences and compromising the flux of ecosystem services produced by mangroves. Through field research it was possible to verify that the logic of aquaculture collides with the forms of use and community perception of the land (family agriculture, fishing, crafts, etc.) that are intimately related to the socialisation of the group. This point follows the principles of reciprocity and community more than competition and individualism. The communities – in small villages and living along the shores of the fluvio-marine system of the Jaguaribe River – depend on the state of conservation of the mangroves and other ecosystems interconnected with them for their survival (Queiroz personal observation). In the Philippines, it has been shown that the profound changes provoked by the disappearance of mangroves (from 400,000 ha around 1920 to less than 100,000 at the beginning of 2000) have provoked important changes including the perception of the environment by the inhabitants of these zones (Farley et al., 2010). Vietnam is another example in which many communities have seen radical changes in their *modus vivendi* due to the shrimp farming industry having replaced artisanal fishing and mangrove organisms with this type of intensive culture (Lan, 2009). The conflicts in this region of SE Asia have been due, above all, to a top-down decision in which the necessities of the people who work (and live) directly from mangrove resources have not been taken into consideration (Lan, 2009).

In the lower Jaguaribe River watershed coastal communities of artisanal fisheries also develop activities such as agriculture and crafts, establishing another type of relationship with nature. They are communities that develop different uses and activities in the mangroves, benefitting from their ecosystem services, for example fishing and shellfish collecting (Aburto-Oropeza et al., 2008; Farley et al., 2010]. These community values and perceptions may be generated by mangroves in different ways, and may be lost with the intensive shrimp farming exploitation that may last a maximum total of 10–15 years (Aburto-Oropeza et al., 2008; Mumby et al., 2004).

In the case of Brazil, the growth of the aquiculture sector was associated with the occupation of the mangrove ecosystem, generating important socio-environmental impacts. Yet, it was impossible to guarantee the sustainability of the activity. These socio-environmental impacts – privatization of water and common-use public lands, the expulsion of ancestral fisher folk and indigenous populations, the systematic deforestation of mangroves, the contamination of water, the decrease in the quantity of fish stocks and the salinization of aquifers – together with the degradation of biodiversity which engenders cumulative effects, may impact the food sovereignty of the communities which find their source of subsistence in mangroves (Polidoro et al., 2010). The situation is very similar, as has been observed, to other places where the identified impacts and their diagnosis due to the intense development of the shrimp farming industry was accelerated

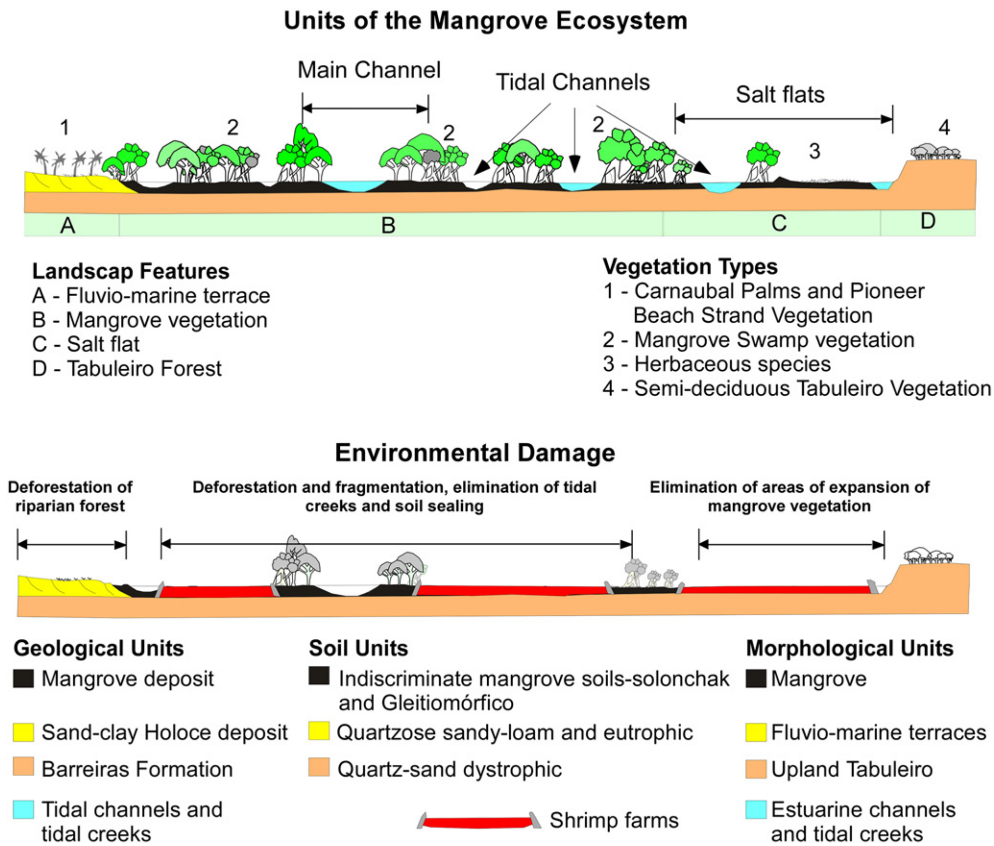

Fig. 6. Mangrove ecosystem units and geological, geo-morphological, soil characteristics, landscape units and vegetation types. Associations were also made regarding the principle environmental impacts related with the introduction of the shrimp farms (Meireles and Tupinambá, 2005; Meireles and Queiroz, 2010).

(Kautsky et al., 2000; Primavera, 2006). As demonstrated in the present study, aquaculture growth in Ceará was especially fast in terms of the disappearance and degradation of mangroves compared to other areas of Brazil and even the rest of the world, although more data is required regarding how it will impact the economic dynamics of the communities of the zone.

In the mid-2000s a retreat in the construction of shrimp farms and production for export was detected. The activity's economic crisis was generated by an accumulation of socio-environmental impacts, as these impacts resulted from a production that the system could not tolerate, just as has been demonstrated in other studies (Rivera-Ferre, 2009). In order to produce more biomass in less time there was an increase in the levels of water pollution in the estuaries, fragmentation of the mangrove ecosystem and the spread of viral diseases introduced by shrimp (EMBRAPA, 2004). For this reason, the shrimp industry, previously presented as one of the most lucrative of the national economy, began to collapse. Recently it has worsened due to the reduction in exports and, consequently, to the abandonment of farms.

The uncontrolled activity is due mainly to the avalanche of farms without environmental permits. The first legal instrument of national scope did not appear until 2002, with Resolution 312 [of the National Environmental Council (CONAMA)]. Farms were also placed in permanent preservation areas, promoting optimism in the producers, to the point that ABCC (ABCC, 2005) stated that the objective was to be the leader of the global market, reaching production equivalent to US$ 1.5 billion by the year 2010. Contrary to the predictions, the value of exports was much lower, reaching US$ 57.6 million. The productive chain degraded rapidly, generating as a consequence financial losses and unemployment due to the rapid decline of an industry that many times was defined as the promoter of the financial redemption of the poorest states of the country.

With the data obtained concerning the economic dimension of shrimp production in mangrove areas, it was possible to confirm that the rapid growth unleashed the collapse of the activity throughout the Jaguaribe River estuary. As environmental responses, accumulated impacts in the ecosystems (water quality and biodiversity loss) and in the communities along the fluvio-marine system (substitution of extractive activities for shrimp monoculture) have been defined. A sequence of environmental and social damage has not yet been quantified in order to thoroughly examine the public policy suggestions locally (estuaries) and regionally (watersheds) in order to measure the economic activities and promote the recuperation of the environmental systems responsible for the bases of productivity of the wetlands and food sovereignty.

Social and environmental externalities need public policies that are aimed at the effective management of fluvial, mixed and marine systems (Naylor et al., 2000). One activity should be measured from the perspective of the advance in new technologies, local alternatives, definition of accumulated impacts; and using the precaution principle and equity, an evaluation of actual social benefit, as well as the environmental and economic benefit of the shrimp monoculture in mangroves can be performed.

The present study associates the rapid growth of shrimp farming in Brazil with the clear degradation of the mangrove system. The example of the state of Ceará produced through a cartographic study (a tool that can be easily used anywhere in the world) is very useful for quantifying the replacement of mangroves with shrimp farms.

The rapid evolution of shrimp farms against mangrove ecosystems minimised the availability of services, compromising the socio-environmental sustainability of the coastal zone of Brazil for the medium-and long-term. The impacts are present not only from the environmental point of view but also from a social and economic one, including an increase in poverty, lack of land and food insecurity, displacement of communities, contamination of potable water, poor working conditions, health and education impacts, and in some countries the violation of human rights.

Acknowledgements

We are especially grateful to Susanne Fietz for a critical view of this manuscript. SR was granted by a Ramón y Cajal contract (RyC-2007-01327). Queiroz, L. receives financial support of Agencia Española de Cooperación Internacional para el Desarrollo (AECID) and National Counsel of Technological and Scientific Development (CNPQ/Brasil). This research has logistical and methodological support of Programa de Pós-Graduação em Geografia da Universidade Federal do Ceará (Fortaleza, Brasil).

References

ABCC, 2004. Projeto executivo para apoio político ao desenvolvimento do camarão marinho cultivado. Associação Brasileiro dos Criadores de Camarão (ABCC), Recife, Brasil. <www.mcraquacultura.com.,br/arquivos/projeto/Marco04.pdf>.

ABCC, 2005. Censo da Carcinicultura 2004. Associação Brasileira dos Criadores de Camarão (ABCC), Recife, Brasil. <http://www. abccam.com.br/TABELAS%20CENSO%20SITE.pdf>.

ABCC, 2010. Estatística do Setor Pesqueiro 2010. Associação Brasileira de Criadores de Camarão (ABCC), Brasil. http://www.abccam.com.br/abcc/images/stories/estatisticas/Estatstica_DO_SETOR_PESQUEIRO.pdf.

Aburto-Oropeza, O., Ezcurra, E., Danemann, G., Valdez, V., Murray, J., Sala, E., 2008. Mangroves in the Gulf of California increase fishery yields. Proceedings of the National Academy of Sciences of the United State of America (PNAS) 30, 10456–10459.

Alongi, D.M., 2002. Present state and future of the world's mangrove forests. Environmental Conservation 29 (3), 331–349.

Alonso-Perez, F., Ruiz-Luna, A., Turner, J., Berlanga-Robles, C.A., Mitchelsonjacob, G., 2003. Land cover changes and impact of shrimp aquaculture on the landscape in the Ceuta coastal lagoon system, Sinaloa, Mexico. Ocean and Coastal Management 46, 583–600.

Arana, L.V., 1999. Aquaculture and Sustainable Development. Editora da Universidade Federal de Santa Catarina, Florianópolis, 310 p.

Austin, B., 1993. Environmental issues in the control of bacterial diseases of farmed fish. In: Pullin, R.V.C., Rosenthal, H., Maclean, J.L. (Eds.), Environmental and Aquaculture in Developing Countries. Proceedings of the 31st International Center for Living Aquatic Resources Management Conference. ICLARM, Manila, Philippines, pp. 237–251.

Barbier, E.B., Strand, I., 1998. Valuing mangrove fishery linkages: a case study of Campeche, Mexico. Environmental and Resource Economics 12, 151–166.

Bardach, J.E., 1997. Sostenible de la Acuicultura. John Wiley & Sons, Nueva Jersey, 251 p.

Braaten, R.O., Flaherty, M., 2001. Salt balances of inland shrimp ponds in Thailand: implications for land and water salinization. Environmental Conservation 28, 357–367.

BRASIL, 2010. Plataforma tecnológica do camarão marinho cultivado: segmento de mercado/Ministério da Agricultura, pecuária e Abastecimento. Departamento de pesca e Aqüicultura, Brasília, Brasil. MAPA/SARC/DPA.CNPq.

Costa-Pierce, B.A., 2002. The 'Blue revolution' – aquaculture must go green. World Aquaculture 66, 4–5.

Ellison, A.M., 2008. Managing mangroves with benthic biodiversity in mind: moving beyond roving banditry. Journal of Sea Research 59, 2–15.

EMBRAPA, 2004. Questões ambientais da carcinicultura de águas interiores: o caso da bacia do baixo Jaguaribe/Ceará, vol. 96. Empresa Brasileira de Pesquisa Agropecuária Fortaleza, Ceará, 51 p.

FAO, 2007. The World's Mangroves, 1980-2005. 153. Forestry Paper. Food & Agriculture Organization of the United Nations (FAO), Rome, Italy. 78 p.

FAO, 2010. The State of World Fisheries and Aquaculture 2010. Food & Agriculture Organization of the United Nations (FAO), Rome. 197 p.

Farley, J., Batker, D., de la Torre, I., Hudspeth, T., 2010. Conserving mangrove ecosystems in the Philippines: transcending disciplinary and institutional borders. Environmental Management 45 (1), 39–51.

Huitric, M., Folke, C., Kautsky, N., 2002. Development and government policies of the shrimp farming industry in Thailand in relation to mangrove ecosystems. Ecological Economics 40, 441–455.

IBAMA, 2005. relatório final. Diagnóstico da Carcinicultura no Estado do Ceará, vol. 1. Instituto Brasileiro do Meio Ambiente e Recursos Renováveis, Brasil. 177 p.

IBGE, 2010. Instituto Brasileiro de Geografia e Estatística. Censo Demográfico. http://www.ibge.gov.br/home/estatistica/populacao/censo2010/default.shtm.

Kautsky, N., Rönnbäck, P., Tadengren, M., Troell, M., 2000. Ecosystem perspectives on management of disease in shrimp pond farming. Aquaculture 191, 145–161.

Laegdsgaard, P., Johnson, C.R., 2001. Why do juvenile fish utilize mangrove habitats? Journal of Experimental Marine Biology and Ecology 257, 229–253.

Lan, T.D., 2009. Coastal aquaculture and shrimp farming in North Vietnam and environmental cost estimation. Aquatic Ecosystem Health & Management 12 (3), 235–242.

Meireles, A.J.A., Cassola, R.S., Tupinambá, S.V., Queiroz, L., 2007. Impactos ambientais decorrentes das atividades da carcinicultura ao longo do litoral cearense, nordeste do Brasil. Revista Mercator 12, 83–106.

Meireles, A.J.A., Queiroz, L., 2010. A monocultura do camarão: danos socioambientais à base da vida comunitária tradicional no litoral do Nordeste brasileiro. In: ZlnourI, Andréa, Laschefski, Klemens (Eds.). Universidade Federal de Minas Gerais (UFMG), Belo Horizonte. 224–249.

Meireles, A.J.A., Tupinambá, S.V., 2005. Impactos da Carcinicultura – Grupo de Trabalho (GT) sobre Carcinicultura. Comissão de Defesa do Consumidor. Meio Ambiente e Minorias da Câmara dos Deputados, Brasil. 117 p.

Meireles, A.J.A., Vicente da Silva, E., 2003. Diagnóstico e impactos ambientais associados ao ecossistema manguezal do rio Acaraú/ce, nas proximidades da comunidade de Curral Velho de Cima. In: Parecer Técnico, Procuradoria da República no Estado do Ceará. Ministério Público Federal, Brasil, p. 32.

Mumby, P.J., Edwards, A.J., Arias-Gonzalez, J.E., Lindeman, K.C., 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature 427, 533–536.

Nagelkerke, C.J., Verboom, J., Van den Bosch, F., Van de Wolfshaar, K., 2002. Time lags in metapopulation responses to landscape change. In: Gutzwiller, K.J. (Ed.), Applying Landscape Ecology in Biological Conservation. Springer Verlag, New York, pp. 330–354.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H., Troell, M., 2000. Efect of aquaculture of world fish. Nature 405, 1017–1024.

Paez-Osuna, F., 2001. The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. Environmental Management 28, 131–140.

Paiva Rocha, I., 2011. Carcinicultura Brasileira: Processos Tecnológicos, Impactos Sócio-Econômicos, Sustentabilidade Ambiental, Entraves e Oportunidades. Associação de Criadores de Camarão em Cativeiro (ABCC). <http://www.abccam.com.br/abcc/images/stories/publicacoes/carcinicultura%20brasileira%20-%20revista%20abcc%20-%20janeiro%202011.pdf>.

Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A.M., Farnsworth, E.J., Fernando, E.S., Kalthiresan, K., Koedam, N.E., Livingstone, S.R., 2010. The loss of species: mangrove extinction risk and geographic areas of global concern. PLoS One 5, e10095. http://dx.doi.org/10.1371/journal.pone.0010095.

Primavera, J.H., 2006. Overcoming the impacts of aquaculture on the coastal zone. Ocean and Coastal Management 49, 531–545.

Rivera-Ferre, M.G., 2009. Can export-oriented aquaculture in developing countries be sustainable and promote sustainable development? The shrimp case. Journal of Agriculture and Environmental Ethics 22, 301–321.

Ronnback, P., 1999. The ecological basis for economic value of seafood production supported by mangrove ecosystems. Ecological Economics 29, 235–252.

Senarath, U., Visvanathan, C., 2001. Environmental issues in brackish water shrimp aquaculture in Sri Lanka. Environmental Management 27, 335–348.

Souza Filho, J., Costa, S.W. da, Tutida, L.M., Frigo, T.B., Herzog, D., 2003. Custo de produção do camarão marinho.Ed. rev. Instituto Cepa/SC/Epagri, Florianópolis. 24 p.

Spalding, M.D., Kainuma, M., Collins, L., 2010. World Atlas of Mangroves. Earthscan, London, UK. 319 p.

Stonich, S.C., Bailey, C., 2000. Resisting the blue revolution: contending coalitions surrounding industrial shrimp farming. Human Organization 59, 23–36.

Valiela, I., Bowen, J.L., York, J.K., 2001. Mangrove forests: one of the world's threatened major tropical environments. Bioscience 5, 807–815.