



Mangrove shrimp farm mapping and productivity on the Brazilian Amazon coast: Environmental and economic reasons for coastal conservation



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ABSTRACT

The present study evaluates the role of marine aquaculture in the conversion of mangrove forests into shrimp (*Litopenaeus vannamei*, Boone, 1931) farms using remote sensing and geographic information system techniques and analyzes the productivity of the installed farms in the mangroves and adjacent coastal plateau. The extension of the shrimp ponds was quantified using satellite image analysis, and the water quality of the shrimp farms was analyzed based on measurements of dissolved oxygen concentration, temperature, pH, and salinity. The productivity of the farms was measured using biometric data. The data were analyzed using ANOVA with Tukey's post-test. The results indicated that shrimp farms cover an area of $\sim 0.8 \text{ km}^2$ (approximately 0.4% of Brazilian ponds), of which 29.4% are located within areas of mangroves, and 70.6% are located in the coastal plateau. Saltwater aquaculture contributed to the conversion of 0.53 km^2 of the mangroves into rearing ponds, which represents only 0.007% of the total area of the Amazonian mangroves. The installations in the mangrove presented significantly higher pH, temperature, transparency, and salinity compared with the ponds installed in the coastal plateau, although coastal plateau ponds had higher dissolved oxygen concentrations. Based on these differences, the mean sizes of the shrimp raised in the mangrove and coastal plateau ponds were 5.7 g and 4.3 g, respectively. However, the estimated value of one hectare of mangrove is much higher than its potential value in the production of shrimp. The considerable value of the ecosystem services provided by the mangroves indicates that the production of shrimp in the coastal plateau is relatively less damaging in ecological and economic terms. Thus, we can consider that the production of shrimp in the coastal plateau instead of in mangrove areas is less damaging to the long-term conservation of mangrove forests, which follows the management best practices established by international organizations. The coastal zone is considered a common resource that belongs to all citizens in Iberoamerican countries, and it is defined as a zone of non-building. Therefore, we conclude that mangroves are more valuable intact than converted into aquaculture ponds. Hence, aquaculture activities in the Amazon coastal plain are not sustainable from environmental and socioeconomic perspectives.

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1. Introduction

Mangrove forests are an extremely valuable natural resource due to their high productivity and fundamental role in the maintenance of the biological diversity of coastal and marine environments (Barbier et al., 2011). The adequate conservation of mangrove habitats is fundamentally important to the ecological

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equilibrium of coastal zones and the maintenance of natural resources and ecological services. These resources sustain important socio-economic activities, such as artisanal and commercial fisheries, aquaculture, and agriculture, and they also provide firewood, building materials, and other products that are exploited for subsistence activities (Saenger et al., 1983; Nagelkerken et al., 2008; Walters et al., 2008).

Due to continuous population growth throughout the world, mangroves are becoming one of the planet's most endangered environments (Valiela et al., 2001). Mangroves have disappeared dramatically in many countries over the past four decades (Alongi, 2002; Barbier and Cox, 2003; FAO, 2007; Gilman et al., 2008). Some countries in Latin America, Asia, and Africa have lost between 30% and 70% of their mangrove forests in the last 40 years (Spalding et al., 2010). The conversion of mangroves into agriculture, aquaculture, and urban areas is the principal factor driving the loss of mangrove habitats worldwide (Barbier and Cox, 2002; Barbier and Sathirathai, 2004; Seto and Frakias, 2007; Giri et al., 2008a,b; Guimarães et al., 2010).

Saltwater shrimp farming is one of the most serious threats to the integrity of mangroves (Primavera, 1997). Shrimp farming has undergone massive expansion in recent years; global production increased from less than nine thousand tons in 1970 to 3.2 million tons in 2007 (FAO, 2008). Asia is the world leader in shrimp farming and produces nearly 80% of the world's farmed shrimp (Biao and Kaijin, 2007). Brazil is 12th in shrimp production, with 69,571 tons in 2011, occupying the 3rd position in the Western Hemisphere, behind Ecuador (260,000 tons) and Mexico (109,816 tons) (FAO, 2013).

The construction of holding ponds for the farming of fish and shrimp is an activity considered to be responsible for the loss of approximately 38% of the world's mangrove forests (Polidoro et al., 2010). In northeastern Brazil, shrimp farming has grown rapidly in recent years; it increased from a total area of 3000 ha in 1997 (an annual production of approximately 4000 tons) to 20,000 ha in 2008 (an annual production of 70,000 tons) (Rocha, 2010). This rapid expansion of shrimp farming activities, together with widespread disregard for environmental legislation, has led to the deforestation of large areas of mangrove habitats and the use of hypersaline areas, locally known as *apicum* (Guimarães et al., 2010; Queiroz et al., 2013).

The increase in production is related to the profitability of aquaculture systems in mangrove environments, which reflects the high value of their ecological services. The high productivity of mangroves and universal ecological illiteracy has led to the widespread underestimation of the economic value of the natural products and ecosystem services provided by mangrove forests (Rönnbäck, 1999). Therefore, intensive shrimp farming, although it is known to be an ecologically and socio-economically unsustainable activity, has been established in many countries (Dahdouh-Guebas et al., 2002; Primavera, 2006). Conversion of mangrove areas into saltwater farms has incited conflicts between shrimp farmers and the traditional communities in other Brazilian areas (Queiroz et al., 2013). However, this situation has not been observed in the Amazon region.

Geographic information systems (GISs) provide a framework for integrating remote sensing and other thematic data. Hence, satellite images with digital maps enable researchers to improve the precision of measurements of the sizes of holding ponds, monitor environmental changes caused by shrimp farming, and identify areas suitable for shrimp farming within mangrove habitats (Kapetsky et al., 1990; Meaden and Kapetsky, 1991; Populus et al., 1995). This research presents the first results of an investigation of the relationship between the environmental parameters of pond waters and shrimp productivity within mangrove and coastal

plateau areas. This analysis is notably important for planning land use in the Amazonian mangrove coast. To define the role of local aquaculture practices in the degradation of the mangroves of the Amazon coastal zone (Fig. 1, A–I), the present study aims to quantify the mangroves and surrounding coastal plateau areas that have been converted into shrimp farming infrastructure using visual interpretations of high-spatial resolution remote sensing images and GIS. Additionally, data on the productivity of saltwater shrimp farms located in these two areas will be compared to determine whether shrimp farming production in mangrove ecosystems is feasible from environmental and socioeconomic perspectives.

2. Study site

2.1. Mangrove land use and specific licensing requirements

Approximately 1.5 million hectares of coastal areas have been converted to shrimp farms, mainly in Thailand, China, Indonesia, and Ecuador (Biao and Kaijin, 2007). Shrimp aquaculture has developed in these countries without regulations or laws in many cases. During the last decade, many authors have found evidence showing that the unsustainability of intensive and semi-intensive shrimp aquaculture methods is contributing to shrimp farm expansion and the degradation of mangrove forests (Barbier and Cox, 2002; Paul and Vogl, 2011; Mialhe et al., 2013). Due to this process, many countries are adopting policies to reduce environmental and socioeconomic impacts on the coastal zone. In the case of Brazil, the uncontrolled activity is mainly due to the influx of farms without environmental permits (Queiroz et al., 2013). The first legal instrument of national scope appeared in 1965, when federal law number 4,771, which instituted the Brazilian Forestry Code, considered mangroves to be an area of permanent preservation. In 1988, the Brazilian National Constitution established that mangroves could only be altered or removed with the permission of the states or municipalities. Later, in 2002, Resolution 312 of the National Environmental Council (CONAMA) reinforced the status of mangrove ecosystems as preserved areas in the Brazilian coast.

2.2. Mangroves and environmental conditions in northern Brazil

In 2009, the total area of Brazilian mangrove forests was approximately 1,071,000 ha (Magris and Barreto, 2010), almost 70% of which was located within the Amazon macrotidal coastal zone (Souza-Filho, 2005). This macrotidal zone extends from Marajó Island to São José Bay and includes 18 environmentally protected areas (Fig. 1). The mangrove flora in this zone consists of six tree species (i.e., *Rhizophora mangle*, *Rhizophora racemosa*, *Rhizophora harrisonii*, *Avicennia germinans*, *Avicennia schaueriana*, and *Laguncularia racemosa*) and many other plants (e.g., *Conocarpus erectus*, *Muellera*, *Rhabdadenia*, and *Acrostichum*) (Menezes et al., 2008).

The climate of the Amazon coast is governed by seasonal shifts in the position of the Intertropical Convergence Zone (ITCZ) and instability lines. The mean annual rainfall in the study area increases from east (2300 mm) to west (2800 mm). The rainy season (January–April) is relatively well defined and accounts for 73% of the annual precipitation. The dry season occurs between September and November when the monthly precipitation is close to zero (Moraes et al., 2005).

2.3. Saltwater shrimp aquaculture and fishery production in Brazil

The commercial cultivation of marine shrimp in Brazil began in the Northeast Region in the early 1970s. The native species initially

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