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Detection of environmental impacts of shrimp farming through multiple lines of evidence

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ABSTRACT

In order to evaluate the impact of semi-intensive shrimp farming, comparisons between Control and Impact areas were made based on multiple lines of evidence using an asymmetrical design. Water and sediment samples were collected in four shrimp farms located in Todos os Santos Bay, Bahia, Brazil. Nutrients, trace elements and macrobenthic assemblages were evaluated using uni- and multivariate analyzes.

Significant differences were observed between Impact and Control areas for the water column dataset (*i.e.*, ancillary variables, SPM, dissolved nutrients and major and trace elements in SPM), whereas no significant differences were observed for the chemistry of sediments. Macrobenthic assemblages were negatively affected by shrimp farm activities. Impacted sites presented the lowest abundance, richness and different structure of macrofaunal benthic assemblages. Farms clearly produced negative impacts in the Todos os Santos Bay. This conclusion was only possible to be reached through the use of multiple lines of evidence. Chemistry and benthic assemblages data combined produced a better description of the quality and impacts of the evaluated environments. Different conclusions would have been reached if chemistry and ecology results were studied separately vs. together.

1. Introduction

Aquaculture contributes expressively to global food security and it has been frequently promoted as a pathway for raising traditional communities profits, improving local food security, and bolstering foreign exchange in tropical developing countries (The World Bank, 2013). Moreover, due to the fast human population growth, environmental degradation and current decline in fish stocks, aquaculture represents an important alternative to meet future demands of high quality proteins (Herbeck et al., 2013; Olsen, 2015), rich in nutrients and fatty acids.

Shrimps have emerged as one of the most valuable globally traded seafood products. Currently, shrimp farming contributes with more than 50% (4.5 billion tonnes) of the total global shrimp consumption (FAO-FIGIS, 2013). The main cultivated species is *Litopenaeus vannamei*, which represents more than 70% of the world production (FAO-FIGIS, 2013; FAO, 2014). China, Indonesia, Ecuador, Vietnam, India, Thailand, Mexico and Brazil are the largest producer (FAO, 2015). In Brazil, the Northeast states (Rio Grande do Norte, Ceará and Bahia States) have been responsible for most of the shrimp cultivation, estimated in 69,000 tonnes in 2012 (Rodrigues and Borba, 2012).

There is considerable potential for the development of shrimp farming in tropical areas such as Northeast Brazil, nevertheless, the debate over its prospective social vs. economical benefits continues owing to the industry's controversial practices (Blythe et al., 2015). Generally, shrimp farms have been developed at the expense of natural habitats, leading to drastic loss of mangrove forests and salt marshes, along with many of their associated ecosystem services (Ha et al., 2014; Polidoro et al., 2010; Senarath and Visvanathan,

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2001). One of the most important services of these ecosystems, and perhaps the least investigated, is their ability to sequester and store C. Destruction of these habitats for the construction of shrimp ponds, among others, may promote the mobilization of C stocks belowground releasing substantial volumes of greenhouse gases and compromising the future sequestration potential of these areas (*e.g.*, Bournazel et al., 2015; Howard et al., 2014 and references herein). Mangrove forests have a much higher economic value than shrimp farms (Huxham et al., 2015; Primavera, 2006). Other impacts associated with shrimp farming are the introduction of exotic species and diseases (Doyle, 2014; Fuller et al., 2014), changes in the composition and quantity of organic matter and contamination by nutrients (Bui et al., 2012; Molnar et al., 2013) and trace elements (Costa et al., 2013; Prapaiwong and Boyd, 2012; Ribeiro et al., 2016) caused by the disposal of untreated wastewater, often laden with pesticides, fertilizers and antibiotics (Graslund and Bengtsson, 2001; Swapna et al., 2012; Thuy et al., 2011). Eutrophication (Herbeck et al., 2013; Smith, 2006) and changes in the structure of benthic assemblages (Freitas et al., 2008; Ribeiro et al., 2016) are also frequently associated to shrimp farm activities. There are also the socioeconomic costs of the shrimp farming, once the traditional coastal communities and the poorest people on the coast are usually dependent on coastal ecosystems, such as mangroves, for both food and income sources. In some regions, mangroves were handed over to shrimp farmers in order to generate private and national profit accumulation through export revenues to the detriment of local populations, particularly women, and the natural environment (Veuthey, 2012). The arguments presented here clearly show that aquaculture systems are complex social-ecological systems, which are characterized by several feedbacks and complex interactions (Blythe et al., 2015; Blythe, 2013; Lebel et al., 2010).

Despite several evidences of negative impacts, few studies have evaluated the effects of shrimp farming simultaneously in key compartments (*e.g.*, water column and benthic environment), and therefore might have overlooked the outcomes and possible differences and relationships between biotic and abiotic variables. In general, these studies focused in a single compartment (*i.e.*, water or sediment) (*e.g.* Aschenbroich et al., 2015; Bui et al., 2012; Herbeck et al., 2013), and/or in the determination of distribution patterns of benthic organisms (*e.g.* Ansah et al., 2012; Tomassetti et al., 2009). Moreover, most of the studies assessing the effects of contamination caused by effluents from shrimp farms lack replication and or independent control areas in order to effectively evaluate potential impacts (Underwood, 1993, 1992).

When assessing the effects of environmental impacts, it is often necessary to use multiple lines of evidence (*e.g.*, Hatje and Barros, 2012; Krull et al., 2014). According to Cook et al. (2012) complex and multifaceted decisions require multiple lines of evidence to support management decisions. Information generated and gathered from different sources, such as chemical analysis of various environmental compartments and benthic communities, is confronted and the combining data helps to improve the understanding of the impact under evaluation. In this study we used multiple lines of evidence (benthic assemblages, nutrients and metal concentrations in sediments and in water) to test the following hypothesis: shrimp farming causes negative impacts (i) in the chemistry of water and sediments and (ii) in the structure of benthic assemblages; and (iii) the impacts of shrimp farms are consistent between different areas (*i.e.* shrimp farms).

2. Material and methods

2.1. Study area

The Todos os Santos Bay (BTS, Fig. 1) is located in the vicinity of Salvador, the third biggest metropolitan area of Brazil. Several anthropogenic activities currently influence the environmental quality of the BTS, such as the influx of domestic and industrial effluents, solid wastes, agriculture, ports and mining activities (Barros et al., 2008; de Souza et al., 2011; Eça et al., 2013; Hatje and Barros, 2012; Hatje et al., 2006a). The municipalities surrounding BTS host more than 60% of the production of shrimp in Bahia State, the third largest producer of Brazil (ABCC/MPA, 2013). The semi-intensive farms (*i.e.*, 6–20 individuals/m^2) are stocked with an exotic species, the Pacific white shrimp *Litopenaeus vannamei*. There are a large number of irregularities associated with aquaculture activities in BTS and most of the farms do not possess legal authorization to operate (IMA, 2009), which made difficult the access to a number of farms and information (*e.g.*, management practices, feed and additives used) regarding the cultivation practices in use.

Four shrimp farm areas, namely Jaguaripe, Jacuruna, Salinas e Acupe (Fig. 1) were studied. All farms present similar production systems (*i.e.*, semi-intensive, with equivalent production around 10 ton/year). Shrimps in these farms are fed with pelleted food and raw protein. Observations *in loco* showed that effluents from farms, without any previous treatment (*e.g.*, sedimentation, bioremediation, water recirculation systems), were discharged in areas adjacent to cultivation ponds (*i.e.*, mangroves, Todos os Santos Bay or its tributaries). The production cycle lasts around 3 months, and occurs between two to three times per year depending on the farm.

2.2. Sample design and sampling

Managers of all four studied farms were contacted in order to obtain information about each farm's operation system. However, with the exception of Acupe, farmers did not disclosure any details of the cultivation process (*i.e.*, feed type and amount, use of fertilizer or additives, date of starting the cultivation cycles). As a result, it was decided to collect all samples at the same period, between April and May 2012, regardless the cultivation stage in operation at each farm.

The asymmetrical sample design (Supplementary Figs. S1 and S2) employed the factors “region” (Re) (Re: random, with four levels, the four studied farms); treatment “Impact (I) vs. Control (C)” (I vs. C: fixed, with two levels: Impact and Control nested in Re), and “location” (Lo) (Lo: random and nested in I vs. C, with one level in I and two levels in C). The sample design for benthic assemblages (Fig. S2) also included a fourth factor named “site” (Si) (Si: random and nested in Lo, with two levels). The control areas were selected based upon the similarities they shared with the farm areas, prioritizing environmental characteristics such as salinity and particle size of sediments. For water and sediment variables, at each farm, for each location, three replicates were sampled 30 m apart from each other. For macrobenthic assemblages four replicates were sampled at each site.

Ancillary variables were measured in situ with a water quality analyzer (Horiba, Model U53). At each site, water samples were manually collected in LDPE bottles. In total, 36 sediment samples were collected with a *van Veen* dredge, stored in LDPE containers and kept frozen until analysis. For macrobenthic assemblages, 96 samples were also collected with a *van Veen* dredge (0.05 m^2; 3.2 L) and carefully sieved in the field with 500 μm mesh. The retained sediment and macrofauna were stored in plastic bags with 70% alcohol. Further sorting were conducted in the lab under stereomicroscope and identifications were mostly to family level, which shows similar patterns as species level (Souza and Barros, 2015).

2.3. Laboratory procedures

All field and laboratory materials were pre-cleaned with a