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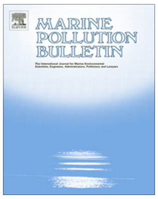

Foraminiferal assemblages as bioindicators to assess potential pollution in mangroves used as a natural biofilter for shrimp farm effluents (New Caledonia)

J.-P. Debenay [a], C. Marchand [b,*], N. Molnar [b,c], A. Aschenbroich [b,c], T. Meziane [c]

[a] *UMR 7159, IPSL/LOCEAN, Centre IRD France Nord, 32 Avenue Henri Varagnat, 93143 Bondy Cedex, France*
[b] *IRD, UR 206 – UMR 7590 IMPMC, F-98848 New Caledonia, France*
[c] *UMR BOREA MNHN-CNRS 7208-IRD-UPMC, Muséum National Histoire Naturelle, CP 53, 61 rue Buffon, 75231 Paris cedex 05, France*

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ABSTRACT

In New Caledonia, semi-intensive shrimp farms release untreated effluents into the mangrove. Foraminiferal assemblages were analyzed for assessing the impact of effluent release on the benthic compartment. Comparison was made between samples collected (1) in an effluent receiving mangrove before and after the rearing cycle, and (2) for one-year monitoring an effluent receiving and a control mangrove. The distribution of foraminiferal assemblages was primarily driven by the gradient between *Rhizophora* stands and salt-flats, related to salinity and tidal elevation, and by seasonal cycles. The potential impact of effluent release was due to the combined effects of normal-saline effluents on surface salinity, and of nutrient input and microbial stimulation on food availability. Foraminiferal assemblages did not indicate a substantial impact of farm effluents and suggest that semi-intensive shrimp farming using mangrove for effluent discharge may appear as a sustainable solution in New Caledonia, when considering only the impact on the mangrove itself.

1. Introduction

The increasing demand for shrimp in the developed countries led to an exponential expansion of shrimp farming, mainly in the subtropical and tropical lowlands. In addition to direct loss of salt-marsh and/or mangrove ecosystems for pond construction, shrimp aquaculture is increasingly criticized for a number of negative impacts (Martinez-Porchas and Martinez-Cordova, 2012). These impacts include the adverse effects of effluents on receiving ecosystems (review in Bui et al., 2012) and the introduction of alien species, either intentionally imported or accidentally introduced. A large portion of nutrients added to a shrimp pond as feed is not converted to shrimp biomass but can be exported from the pond system as particulate and dissolved nutrients, where it can be responsible for excess primary productivity, and even harmful algal blooms (Jackson et al., 2003; Costanzo et al., 2004; Casillas-Hernández et al., 2007; Miranda-Baeza et al., 2007; Hasani et al., 2012; Bui et al., 2013). Shrimp pond effluents, high in organic matters, also have a high biological oxygen demand and can cause oxygen depletion in receiving waters (EJF, 2003), where eutrophication is often cited as a major concern (Páez-Osuna et al., 1998; Mckinnon et al., 2002; Bui et al., 2012; Herbeck et al., 2013). Thus, spatial and temporal assessment of coastal aquatic environments in shrimp farming areas is essential for protecting estuarine and marine ecosystems and promoting a sustainable economic development (Boyd and Green, 2002).

The use of natural mangroves as biofilters for shrimp pond effluents is considered as an efficient tool for reducing the impact of shrimp farming (Páez-Osuna, 2001; Gautier, 2002). They remove significant percentages of total suspended solids (Gautier et al., 2001), and several authors have reported their effectiveness in removing nutrients and pollutants from effluents (e.g. Tam and Wong, 1999; Wang et al., 2010; Zaldívar-Jiménez et al., 2012). Constructed on salt-flats, shrimp ponds are not responsible for mangrove deforestation in New Caledonia, but induce topographical and hydrological transformations that may cause changes in faunal composition at all levels (meiofauna, macrofauna, megafauna) (Virly et al., 2005). Semi-intensive shrimp farming of the blue shrimp *Litopenaeus stylirostris* typically uses a flow-through system with water exchange rates as a tool to maintain optimum hydrological and biological parameters for the crop (Della Patrona and Brun, 2008; Thomas et al., 2010). Water supplies consist of open-sea water that keeps salinity of the ponds

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* Corresponding author.
E-mail address: cyril.marchand@ird.fr (C. Marchand).

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between 32‰ and 39‰. Water renewal varies from 0% to 30% per day, depending on shrimp biomass. Untreated effluents, mostly composed of normal saline water, are released into the mangrove that has been demonstrated to be only a partial filter for the shrimp farm effluent leaving part of the nutrient loads exported to the adjacent bay (Molnar et al., 2013). In addition to nutrient enrichment, the release of effluent within the *Avicennia* stand, by modifying the length of water-logging, modifies the redox conditions as well as the salinity of pore-waters, and thus modify the ecological conditions of the mangrove benthic compartment (Marchand et al., 2011a; Molnar et al., 2014).

Because of their short life and reproductive cycles, high biodiversity and specific ecological requirements, benthic foraminifera are particularly sensitive to changing environment. Density, diversity and composition of the communities may change rapidly in response to changes in environmental conditions, making them valuable environmental bioindicators of environmental stress, both natural and anthropogenic (e.g., review in Frontalini and Coccioni, 2008; Carnahan et al., 2009). Despite the difficulty in deconvoluting the impact of pollution from natural stress (Armynot du Châtelet and Debenay, 2010), a number of studies conducted since the 1960s has demonstrated their usefulness as proxies for coastal monitoring (reviews in Nigam et al., 2006 and Pati and Patra, 2012). Foraminiferal assemblages from low-latitude intertidal mangrove swamps have been studied for long in various regions (reviews in Debenay et al., 2004 and Woodroffe et al., 2005). They can show an intertidal zonation (e.g. Hayward et al., 1999; Horton et al., 2003; Woodroffe et al., 2005), but major factors independent from elevation, such as their sensitivity to spatial (horizontal) or temporal changes in salinity may have a greater influence on their distribution trends (e.g., Debenay and Guiral, 2006; Culver et al., 2012). Only a few studies have been carried out on benthic foraminifera specifically related to aquaculture (e.g., Schafer et al., 1995; Scott et al., 1995; Angel et al., 2000; Bouchet et al., 2007; Vidović et al., 2009), and even less related to the impact of shrimp farms (e.g., Luan and Debenay, 2005; Souza et al., 2010). Recently, studies carried out in shrimp ponds from New Caledonia have shown that they are rapidly colonized by a few foraminiferal species, but that the individuals growing in the ponds may be strongly deformed, indicating adverse environmental conditions mostly due to the accumulation of easily oxidized material (Debenay et al., 2009a,b).

The aim of this study was to investigate the impact of shrimp farm effluent discharge on the benthic compartment of a mangrove using foraminiferal assemblages as bioindicators. Firstly, samples were collected throughout the different mangrove stands after a period of several months without effluent discharge and after a period of several months of rearing; assemblages of the two periods were compared. The results were compared to geochemical analyses (Chl-a content, fatty acids distribution, carbon and nitrogen stable isotopes) carried out on the same samples in previous studies (Molnar et al., 2014; Aschenbroich et al., 2015). Secondly, changes in the assemblages from an *Avicennia* stand was monitored over a one-year period, during and after the rearing period, in the impacted mangrove and in a neighboring control mangrove. The *Avicennia* stand was chosen because it is the closest stand from the salt-flat where the ponds are constructed.

2. Material and methods

2.1. Study site and sampling

New Caledonia (south-west Pacific) typically experiences easterly to southeasterly winds, with a tropical humid climate on the east coast, and a semi-arid climate on the west coast. The hot rainy season is from January to March, while a cooler, drier time occurs from May to October, with the winter season in July to August. However, the dates and duration of each season, as well as rainfall intensity may considerably vary from one year to another. Yearly rainfall on the leeward southwest coast, where the study was carried out, varies from 800 to 1200 mm. During our study, rainfalls were particularly intense at the end of the rainy season 2009 (February–March), and in July, but were particularly low during the rainy season of 2010 (Fig. 1). The tidal regime is semi diurnal, unequal, and low mesotidal (maximum tide value is 1.6 m) (Douillet, 1998). During the study period, the levels of both high tides and low tides were the lowest during the dry season (May–October), leading to a downward shift of about 15 cm of the intertidal zone (Fig. 1). Owing to the very flat slope of the mangrove, this vertical shift may produce significant horizontal offsets resulting in differences in the duration of tidal immersion.

Extensive mangroves are fringing 88% of the low western coastline of the main island, sheltered from the easterlies winds. They cover 35,100 ha, including 9200 ha of salt marshes and salt-flats (Virly, 2008), and exhibit the typical zonation of mangroves in semi-arid conditions with *Rhizophora* spp. in the low intertidal zone, *Avicennia* spp. in the intertidal zone, *Sarcocornia quinqueflora* on the salt marshes, and bare salt-flats at the higher tidal elevation. The *Rhizophora* and *Avicennia* stands are subjected to tidal cycles whereas salt-flats are more irregularly immersed, which leads to higher salinity levels.

The study was conducted in two bays located on the west coast of New Caledonia, both occupied by a mangrove forest and with insignificant freshwater input (Fig. 2). The first one (A) of about 20 ha in surface area and virtually free of anthropogenic influences was used as a control area (Fig. 2A). The second one (B) of about 29 ha in surface area receives the effluent discharges from the FAO shrimp farm (Ferme Aquacole de la Ouenghi). The FAO shrimp farm opened in 1989. It operates two 1 m deep rearing ponds of 10.5 ha (L) and 7.5 ha (K) respectively. The rearing cycle lasts about eight months (December–July), and ends during the cool season in order to prevent diseases and bacterial growth. At the end of the cycle, the ponds are partially drained during each of the 2–12 partial harvests. After the last harvest, they are completely drained out and left to dry for several weeks. Untreated effluents are discharged at multiple points, either released directly into the mangrove or collected in the effluent channel, often spilling out over the channel banks at high tide (Fig. 2B and C). A levee partially separates the inner bay, which receives shrimp effluents, from the outer bay, which opens to Saint Vincent bay.

Five reference stations were selected in the *Avicennia* zone of each mangrove A (control) and B (impacted) for a one-year monitoring. They were sampled eight times during the 2009 rearing cycle, when both ponds L and K were in production (Figs. 1 and 2). In addition, surface sediment samples were collected at low tide, at 51 locations in the whole mangrove B, for a dual-season mapping of foraminiferal assemblages. Samples were collected before the beginning of a rearing cycle in December 2009 (Non Active Period – NAP), and at the end of a rearing cycle in July 2010 (Active Period – AP) (Fig. 2C). Due to a shortage of shrimp larvae, only pond K was in production during AP. The sites were selected following a random sampling procedure, but because of the high density of trees and aerial roots, several sites were not accessible and the use of a systematic sampling approach (Caeiro et al., 2003) was therefore not always possible. Sampling points were recorded using a handheld GPS (Colorado 300, Garmin).

2.2. Methods

Each sample for foraminiferal analyses was composed of surface sediments collected randomly over a 1 m^2 surface area. The upper