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The role of bioturbation by *Ucides cordatus* crab in the fractionation and bioavailability of trace metals in tropical semiarid mangroves

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ABSTRACT

This study evaluated the burrowing activity of *U. cordatus* and its effects on Fe, Cu and Zn fractionation, bioavailability and bioaccumulation in a semiarid mangrove area (Ceará state, NE-Brazil). Were analyzed the Eh; pH; grain size and pore water composition; total S and organic C, and the speciation of Fe, Cu and Zn solid-phases in two areas: a densely populated crab and a control site. The burrowing activity and seasonal variation affect the biogeochemical conditions of mangrove soils increasing metals bioavailability and bioaccumulation. The crab burrows favors the entrance of oxygen into the soil, oxidizing the pyrite and forming poorly-crystalline Fe minerals, increasing the risks of biocontamination. Furthermore, the metals content in the hepatopancreas are a good proxy for the evaluation of bioavailable metal forms and, thus, further studies must be conducted in order to evaluate the potential use of *U. cordatus* as a bioindicator for trace metals contamination.

1. Introduction

Mangrove forests are among the most important coastal ecosystems in the world, covering extensive areas in tropical and subtropical regions (Spalding et al., 1997). Associated to these ecosystems, brachyuran crabs (mostly fiddler and sesarmid crabs) stand out as the most conspicuous among the Crustaceans (Ahyong et al., 2007), and are key organisms for the mangrove functioning since they influence many biogeochemical processes (Kristensen and Alongi, 2006; Pülmanns et al., 2014). This fact caused the recent recognition of mangrove crabs as true ecosystem engineers (Kristensen, 2008).

Among the wide range of influences that Brachyurans exert in mangrove ecosystems (i.e. through leaf consumption, propagule predation, pre-shredding and macerating leaf-litter), the bioturbation probably stands out with the greatest number of co-effects. The biological mixing of soil and sediments during the construction and maintenance of burrows for different purposes (refuge, mating, feeding) and its physical and chemical effects have received a great deal of attention in the last few years (Wilson et al., 2012; Quintana et al., 2015; Remaili et al., 2016; Martinez-Garcia et al., 2015).

In fact, recent studies have evidenced that bioturbation in mangrove substrates may considerably deviate the dominance of anaerobic respiration routes (i.e. sulfate reduction; Kristensen, 2008) to others more energetically favorable (i.e. aerobic and iron reduction; see Alongi et al., 2001; Kristensen, 2000; Quintana et al., 2015). Furthermore, as bioturbation promote the oxidation and dissolution of the sulfidic material (i.e., pyrite; Araújo et al., 2012), an important trace metal sink (Machado et al., 2014), it may also increasing trace metals bioavailability. Thus, crab burrowing activity may not only alter the predominance of anaerobic pathways, but directly affect trace metals behavior with an associated risk of increasing their mobility and environmental impacts.

Among these crabs, *Ucides cordatus* stands out as the most extensively distributed along the Brazilian coast (Melo, 1996), and as one of the most dominant burrowing decapod inhabiting mangrove forests in the tropics. Despite the effects of *U. cordatus* burrows in mangroves soil has been studied (Pülmanns et al., 2014; Araújo et al., 2012), any studies have been conducted in order to assess the effects of bioturbation on metals bioavailability and, thus, the effects of crab bioturbation on metal biogeochemistry in mangrove soils still poorly understood. This study aim to evaluate the burrowing activity of *U. cordatus* and its effects on Fe, Cu and Zn fractionation, bioavailability

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and bioaccumulation rates in a semiarid mangrove area improving the comprehension of these endangered ecosystems and, thereby, promoting better conservation policies and management practices.

2. Material and methods

2.1. Study site

The sampling site is located at the Jaguaribe river estuary, Ceará State, NE Brazil (Fig. 1). The semi-arid climate of the region (Alvares et al., 2013) presents a rainy period with a mean rainfall of 734 mm (from February to April) and a dry season with an mean rainfall of 189 mm (from June to January) with annual temperatures ranging from 26 °C to 28 °C (IPECE, 2014). The mangrove forest in the Jaguaribe estuary covers 1735 km^2 (Maia et al., 2006) and is dominated by *Rhizophora mangle* L., *R. racemosa*, and *Avicennia schaueriana* L. species, and the spring-neap tidal cycle ranges between 1.4 and 2.6 m (Tanaka and Maia, 2006).

The Jaguaribe estuary stands out as the largest shrimp producer in Brazil (Lacerda et al., 2009; Nogueira et al., 2009) with a total of 12.6 km^2 of ponds, accounting for 12% of the national shrimp production (Nogueira et al., 2009). Most shrimp ponds are in close contact with mangrove forests that are permanently exposed to heavy metal emissions. In fact, the chronic use of Cu-bearing aquafeeds and fertilizers during shrimp breeding were reported as the main causes for high Cu contents in some Brazilian mangrove ecosystems (Lacerda et al., 2006). Moreover, due to physiological requirements, most shrimp species require a Zn-supplementation (Friberg et al., 1974), which frequently results in a large concentration of this metal in shrimp pond effluents.

2.2. Sample collection

Since there are no baseline concentrations for these potentially toxic metals in semiarid mangrove soils affected by shrimp pond effluents and no assessment of the effects of bioturbation on these metals dynamics, soil samples were collected in two contrasting sites: one affected by crab burrowing activity ("crab site" - Cb) and another without crab activity ("control site" - Cs). Both sites were closely located (distance <10 m) maintaining identical physiographical position to avoid differences in flooding frequency, and to minimize vegetation effects (e.g., presence of pneumatophores, roots and plantlets). The sampling sites are vegetated by *Rhizophora mangle* and directly influenced by the shrimp farming effluents discharge from 28 shrimp ponds (covering 66.5 ha) (Fig. 1C). However, all the shrimp farms at the Jaguaribe River are located upstream to the sampling site, which conducts to an intense anthropogenic metal discharge at the study site (Lacerda et al., 2006).

The burrow density was determined and the burrows depths were measured with a soft rubber wire (Branco, 1993), whereas the superficial crab burrow diameters were measured with a caliper (Carmona-Suárez and Guerra-Castro, 2012). In the control site, bioturbation was avoided by the establishment of an exclusion plot by fencing off the soil with a 1 cm mesh nylon net (0.1 m height above the substrate and buried up to 1.5 m of depth) during 3 months prior to soil sampling. Six soil cores (PVC tubes with 5 cm diameter and 50 cm length) were taken in each site during low tide, with soils exposed to the atmosphere, during the wet and dry seasons (May and December, respectively) in 1 m^2 plots. The cores were cut into sections of 10 cm depth intervals (0–10, 10–20 and 20–30) for laboratory analysis. The redox potential (Eh) and pH were measured in situ after equilibrating the electrodes for approximately 2 min with the soil samples. The redox potentials

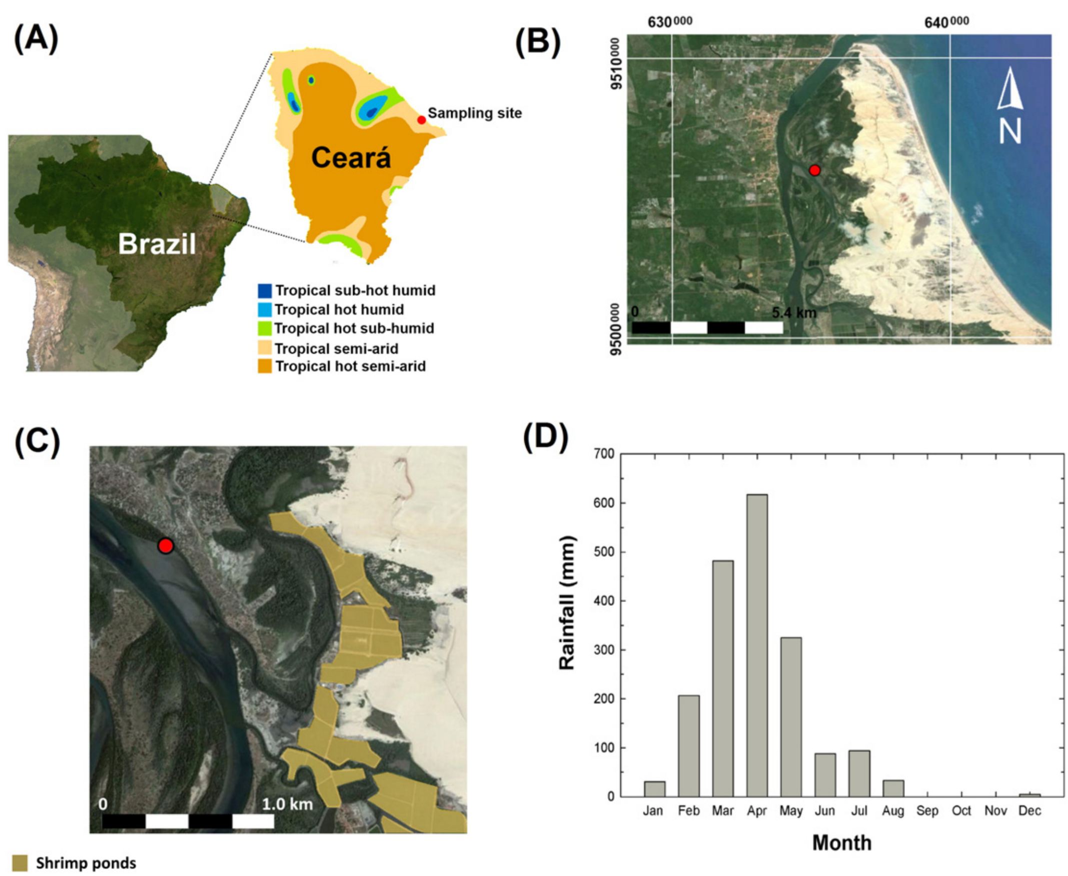

Fig. 1. Location of the Jaguaribe estuary (A) and the sampling site (B) in the Ceará State (northeastern Brazil); In detail, shrimp ponds near to the sampling site (C); and precipitation record for the 2009, in mm (D).