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Functional traits of selected mangrove species in Brazil as biological indicators of different environmental conditions

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HIGHLIGHTS

- We investigated adaptive modifications in plants in response to differences among three estuaries.
- We used pattern recognition methods to match differences among estuaries with plant adaptations.
- *A. schaueriana* and *L. racemosa* are good bioindicators of differences among studied estuaries.
- Dry mass per leaf area (LMA) in *A. schaueriana* was the better indicator of adaptive modifications.

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ABSTRACT

Ecological studies on phenotypic plasticity illustrate the relevance of this phenomenon in nature. Conditions of biota reflect environmental changes, highlighting the adaptability of resident species that can be used as bioindicators of such changes. We report the morpho-anatomical plasticity of leaves of *Avicennia schaueriana* Stapf & Leechm. ex Moldenke, *Laguncularia racemosa* (L.) C.F.Gaertn. and *Rhizophora mangle* L., evaluated in three estuaries (Vitória bay, Santa Cruz and Itaúnas River; state of Espírito Santo, Brazil), considering five areas of mangrove ecosystems with diverse environmental issues. Two sampling sites are part of the Ecological Station Lameirão Island in Vitória bay, close to a harbor. A third sampling site in Cariacica (Vitória bay) is inside the Vitória harbor and also is influenced by domestic sewage. The fourth studied area (Santa Cruz) is part of Piraquê Mangrove Ecological Reservation, while the fifth (Itaúnas River) is a small mangrove, with sandy sediment and greater photosynthetically active radiation, also not strongly influenced by anthropic activity. Results pointed out the morpho-anatomical plasticity in studied species, showing that *A. schaueriana* and *L. racemosa* might be considered the most appropriate bioindicators to indicate different settings and environmental conditions. Particularly, the dry mass per leaf area (LMA) of *A. schaueriana* was the main biomarker measured. In our study, LMA of *A. schaueriana* was positively correlated with salinity (Spearman 0.71), Mn content (0.81) and pH (0.82) but negatively correlated with phosphorus content (−0.63). Thus, the evaluation of modification in LMA of *A. schaueriana* pointed out changes among five studied sites, suggesting its use to reflect changes in the environment, which could be also useful in the future to evaluate the climate change.

1. Introduction

Phenotypic plasticity includes all types of environmentally induced phenotypic variation (Stearns, 1989), and when beneficial to an individual, it is referred to as adaptive phenotypic plasticity (Pigliucci, 2001). Two approaches are given in the study of phenotypic plasticity: 1) traditional, *sensu stricto* (*e.g.*, Pigliucci, 2005; Richards et al., 2006), focusing on the evolution or on the mechanisms underlying the plastic response, and 2) ecological (*e.g.*, Bell and Galloway, 2008; González and Gianoli, 2004), focusing on the patterns of population differentiation in plasticity along an environmental gradient. Because it includes a broader range of study systems, the latter approach contributes to the understanding of the ecological significance of phenotypic plasticity in addition to providing a comprehensive view of its relevance in nature (Gianoli and Valladares, 2012).

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In mangrove swamps, variation in forest structure along an environmental gradient partly depends on the capacity of each plant species to exhibit adaptive phenotypic plasticity to physical and chemical conditions (Ball, 1996, 2002; Christian, 2005; Lovelock et al., 2005). Usually, mangrove ecosystems are characterized by the presence of waterlogged, clayey, saline sediments with high levels of organic matter. However, these factors can vary widely between areas. Plants can be established in various substrates, including sand, peat, volcanic lava and carbonate sediments (Woodroffe, 1992). Plants living in mangrove ecosystems may be subjected to broad salinity fluctuations (Ball, 1998). This characteristic can be influenced by the distance of the mangrove forests from the sea (Bernini et al., 2010), by the distance of individuals from the edge of the forest (Sam and Ridd, 1998), rainfall patterns and overland freshwater input (Semeniuk, 1983). Furthermore, pollution, produced by organic waste or heavy metals, may change the concentration of certain elements and modify the bioavailability of nutrients (Laing et al., 2009; Pan and Wang, 2012). In addition to edaphic factors, solar radiation also varies, primarily due to the spatial distribution of vegetation and the characteristics of the canopy (Lima and Galvani, 2013). Variation in environmental factors can thus lead to adaptive responses by the plants (Feller et al., 2010).

Many anatomical studies including *Avicennia schaueriana* Stapf & Leechm. ex Moldenke, *Laguncularia racemosa* (L.) C.F.Gaertn. and *Rhizophora mangle* L. deal with descriptive aspects of their organs (*e.g.* Evans and Bromberg, 2010; Francisco et al., 2009; Menezes, 2006; Tomlinson, 1994; Tomlinson and Cox, 2000). Studies on the influence of environmental factors on the anatomical or morphological characteristics of leaves have been reported by Ellison and Farnsworth (1997), Farnsworth et al. (1996), Sobrado (2005, 2007) and Werner and Stelzer (1990). However, reports analyzing these plants *in situ* are still scarce (Camilleri and Ribi, 1983; Farnsworth and Ellison, 1996; Feller, 1996).

Therefore, this study aimed to assess the morpho-anatomical plasticity of leaves of *A. schaueriana*, *L. racemosa* and *R. mangle* in five areas of mangrove ecosystem in Brazil, which are affected by different environmental conditions. The hypothesis was that differences in environmental conditions trigger adaptive modifications in leaves, which can be used to evidence alterations in their environments.

Thus, we looked to assess which plant could be used as a good bioindicator of differences in environmental issues as well as identifying adaptive features that could be used as biomarkers of such differences. What sets this study apart from other studies is that we investigated not only adaptive modifications in plants but also differences in the corresponding environments, using a combined set of multivariate methods (pattern recognition) to match differences in the environment with adaptations in plants, looking to identify the better bioindicator and also to point out suitable biomarkers.

2. Materials and methods

2.1. Study area

Five mangrove ecosystem sites located in four municipalities belonging to the state of Espírito Santo were selected for this study: Vitória, Cariacica, Aracruz, and Conceição da Barra. Three different estuaries are located within this area: Vitória bay, Santa Cruz and Itaúnas River (Fig. 1). Two sampling sites were chosen within the municipality of Vitória, which are part of the Ecological Station Lameirão Island: one located at the Passagem Channel (Fig. 1, site 1) (20°17′35.7″S and 40°19′12.8″W) and the other is on Lameirão Island (Fig. 1, site 2) (20°15′00.6″S and 40°19′08.6″W). The sampling site in Cariacica (Fig. 1, site 3) (20°19′35.8″S and 40°22′13.0″W) is influenced by a direct input of domestic sewage. This last site, along with those on Lameirão Island and at the Passagem (exchange) Channel, is part of the estuary system of the island of Vitória, which covers an approximate area of 18 km^2. The mangrove ecosystem in Aracruz covers approximately 12 km^2 and contains the Piraquê-Açu and Piraquê-Mirim River estuaries. This sampling site (Fig. 1, site 4) (19°56′26.2″ S and 40°13′27.0″ W) is in the Piraquê-mirim River estuary, which is part of Piraquê-Açu and Piraquê-Mirim Mangrove Ecological Reservation. In Conceição da Barra, the site chosen (Fig. 1, site 5) (18°33′55.2″S and 39°44′38.1″W) is at the mouth of the Itaúnas River, known as Guaxindiba Beach. It is a small mangrove wood, approximately 30 m from the sea, on sandy sediment and with less dense vegetation than other studied sites (sites 1–4). All sites sampled have a tidal amplitude lesser than 2 m (Marinha do Brasil, 2010), classified as microtidal.

According to Kottek et al. (2006), the climate classification in the state of Espírito Santo, Brazil, is equatorial (A); equatorial savannah with dry winter – Aw (precipitation of the driest month less than 60 mm in winter) in Vitória, Cariacica and Aracruz, and equatorial

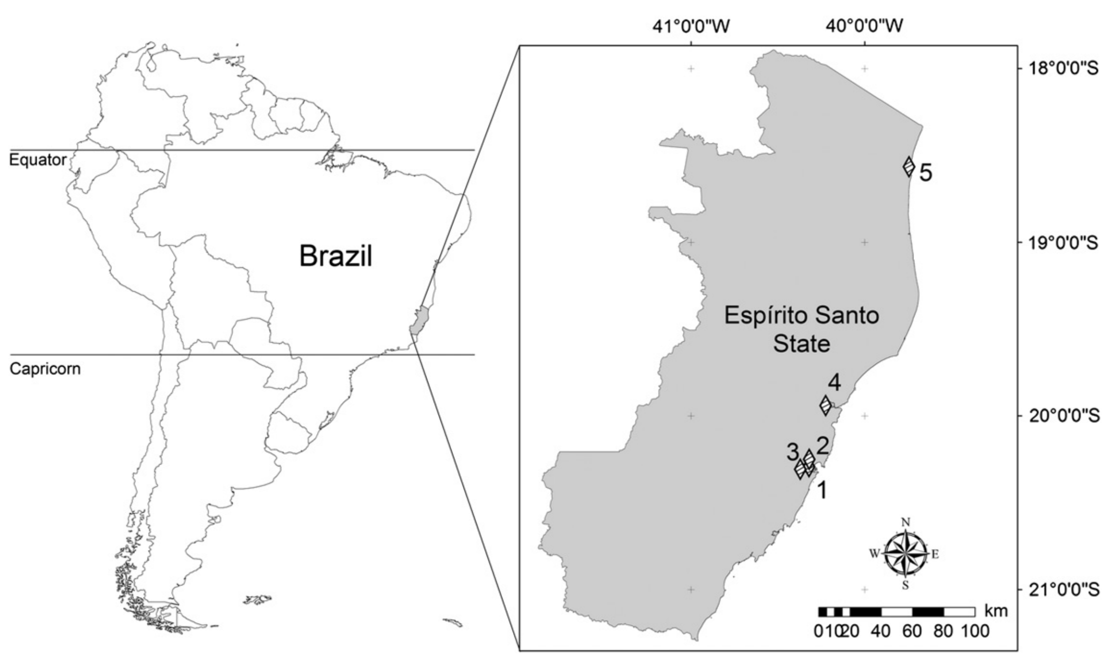

Fig. 1. Map of Brazil and Espírito Santo with the location of the sampling sites in this study (1 = Passagem Channel; 2 = Lameirão Island; 3 = Cariacica; 4 = Aracruz; 5 = Conceição da Barra).