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Tropical trees: Are they good alternatives for biomonitoring the atmospheric level of potential toxic elements near to the Brazilian Atlantic Rainforest?

Ricardo K. Nakazato*, Mirian C.S. Rinaldi, Marisa Domingos

Instituto de Botânica, Núcleo de Pesquisa em Ecologia, Caixa Postal 68041, 04045-972 São Paulo, SP, Brazil

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ABSTRACT

The foliar accumulation and enrichment factor for 36 elements were studied in *Psidium guajava* 'Paluma' (fruit tropical tree) and *Tibouchina pulchra* Cogn. (native tree of the Atlantic rainforest) plants exposed around the city of Cubatão/Brazil, to propose a biomonitoring species in the Atlantic rainforest. The field experiments were conducted in six sites from November/2009 to April/2011. Parallel exposures of plants to filtered air in open-top chambers were performed to determine the background leaf concentrations of all elements. Both plants were enriched with elements (Ni, La, Fe, Ba, Al, Co, Pb, Hg and Mn) that characterize the industrial area of Cubatão, Brazil. *P. guajava* is a better option for biomonitoring toxic elements in Cubatão, since it was able to enrich higher metal levels than *T. pulchra*. Furthermore, *P. guajava* showed a better spatial and temporal variations in metal levels Cubatão.

1. Introduction

The atmosphere in industrial and urban centers is contaminated by a wide variety of pollutants, including nitrogen and sulfur gaseous compounds and particulate matter, all forming a complex mixture which may contain sulfate, nitrate and metals, among others. Researchers of the nineteenth century had already reported the high susceptibility of higher plants to air pollutants, a characteristic that has been employed worldwide for air pollution biomonitoring ever since. Accumulator plants are specially interesting for such purposes because they have physiological, biochemical, and/or morphological mechanisms which increase their ability to survive in contaminated environments while resulting in high leaf accumulation of toxic elements from air pollution (Cape, 2009; Ingenieure, 2003; Markert, 2007; Markert et al., 2003; Shugart et al., 1992; Temmerman and Hoenig, 2004; Weiss et al., 2003). By observing and measuring leaf accumulation of toxic elements, it is possible to draw conclusions about pollutant sources and levels of air contamination (Markert, 2007), as demonstrated by Abril et al. (2014), Lodenius (2013), Nakazato et al. (2015), Noth et al. (2013), and Sutton et al. (2014), among many other authors. In recent decades, some biomonitoring programs based on responses of accumulator plants have been performed in SE-Brazil, such as those conducted around a large worldwide-known industrial complex located in Cubatão city (Araújo et al., 2008; Domingos et al., 2003a; Esposito and Domingos, 2014; Klumpp et al., 2002; Nakazato et al., 2015; Rinaldi et al., 2012; Silva and Moraes, 2013; Silva et al., 2013). As a result of those investigations, Domingos et al. (2015) and Nakazato et al. (2015) concluded that the standardized ryegrass culture (*Lolium multiflorum* ssp. *italicum* cv. Lema) is adequate for monitoring the biological risks posed by toxic elements associated with industrial, urban, and agricultural sources of particulate matter in the most developed state in SE-Brazil (São Paulo). However, it is plausible to assume that L. *multiflorum* cv. Lema, of temperate origin, would offer a less advantageous risk analysis, focusing on tropical forest ecosystems, than would tropical accumulator trees, even considering that the biomonitoring protocol for ryegrass cultivation and exposure (Ingenieure, 2003) has been shown to be applicable to the tropical region. In addition, local seed producers are not available, restraining the routine use of *Lolium* Lema as a biomonitor in Brazilian polluted regions. Therefore, the potential of tropical plants for biomonitoring toxic elements should be assessed. Previous studies were performed based on the foliar accumulation of toxic elements in tropical plants, like *Tibouchina pulchra* Cogn., a tree species native to the Atlantic Rainforest (Domingos et al., 2003b, 1998; Furlan et al., 2004; Klumpp et al., 1996a, 1996b, 2002), and *Psidium guajava* (Bulbovas et al., 2015; Moraes et al., 2002). These plants appeared to be adequate biomonitors of nitrogen, sulfur, fluorine, and a few metals, mostly

* Corresponding author.
E-mail address: ricardo.nakazato@outlook.com (R.K. Nakazato).

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micronutrients. However, it remains unknown which of them would be the most efficient tree species in accumulating the large variety of toxic elements usually deposited in complex industrial/urban/agricultural areas currently existing in Brazil and other developing countries in the tropics. Also, both species lack a standardized biomonitoring protocol, despite having a great ecological relevance in those areas. Therefore, we aimed to: (1) comparatively evaluate the capacity of *P. guajava* and *T. pulchra* saplings exposed to polluted sites for accumulating potentially phytotoxic elements, by calculating enrichment factors; (2) indicate the most adequate among both species for biomonitoring the biological risks posed to the Brazilian Atlantic Rainforest, by analyzing marker elements from several anthropogenic emission sources, based on correlations with air pollutant concentrations and on the expected spatial and temporal variations previously determined by Nakazato et al. (2015), which should be applicable to other tropical forest ecosystems.

2. Materials and methods

2.1. Study area and biomonitoring design

Field experiments were performed in Cubatão city, which is located in São Paulo state, SE-Brazil (23°45′-23°55′ S; 46°21′-46°30′ W), in a coastal plain surrounded by slopes of a mountain range regionally known as Serra do Mar. This region was selected for the study due to the well-defined distribution of pollution sources (Nakazato et al., 2015) and to the occurrence of large portions of Atlantic Rainforest, which needs to be preserved in view of its high biodiversity, on the slopes of Serra do Mar. An industrial complex composed of more than 20 different industries is present in the region, totalizing around 260 sources of air pollutants (CETESB, 2013; Silva et al., 2013). Furthermore, intense car traffic also contributes to local air pollution (Nakazato et al., 2015). Field experiments were conducted in six sites: CM5, CM3, and CM1 are located at Caminho do Mar Road and are influenced by oil refinery and thermoelectric emissions; CEP and CET are located next to major roads of Cubatão and some industries; and RP is located at Serra do Mar State Park and is influenced by traffic emissions. These sites are represented in Fig. 1.

Climate in the region is tropical without dry season (Af type, according to Köppen's classification), with high relative humidity, high annual rainfall (2600 mm), and an average annual temperature of around 23 °C (Alvares et al., 2013). Wind blows in opposite directions over a 24-h period. Stronger winds blow from S and SW to NE during the day, and weaker winds blow from NE to SW at night. These wind patterns determine the dispersion of pollutants emitted by the industrial complex and vehicular traffic. Therefore, the Atlantic Rainforest that covers the slopes of Serra do Mar are directly affected by air pollutants emitted in Cubatão. Air pollutant concentrations tend to be higher during winter and less rainy months (CETESB, 2013).

Tibouchina pulchra Cogn. (manacá-da-serra) and *Psidium guajava* cv. Paluma (guava) were the two tropical tree species selected for this study. The former is a Melastomataceae species from the Atlantic Rainforest that occurs in large numbers even in polluted areas in the region (Domingos et al., 2003a, 1998; Furlan et al., 2004). The latter is a Myrtaceae of tropical American origin which is commonly cultivated for fruit production in Brazil (Moraes et al., 2002; Perry et al., 2010) and has also been found near the Atlantic Rainforest in Cubatão.

Saplings of *T. pulchra* (provided by the São Paulo State Energy Company – CESP) and *P. guajava* (provided by a commercial producer) were obtained at similar developmental stages (with an average 20 cm stem height and 4–6 leaves on the main stem). All saplings were transplanted one month before the beginning of each field experiment to plastic pots using standard substrate (a mixture of a commercial substrate – primarily composed of *Pinus* bark – and fine vermiculite, in a 3:1 ratio). Throughout cultivation, saplings were kept inside a glasshouse under filtered air and adequate temperature conditions for their growth, kept by means of air conditioning. Saplings were continuously watered by nylon strings that connected the bottom of the pots to water reservoirs. These procedures were performed repeatedly to obtain similar plant lots for all field experiments.

After adaptation to transplanting conditions, six potted saplings of *T. pulchra* were exposed in each site for 84 days on aluminum racks, covered by a shade net on the top and on N, E, and W sides, in order to protect plants against excessive radiation (50% of reduction), following the design described by Arndt and Schweizer (1991). Six potted saplings of *P. guajava* were exposed in the field, following the procedure described for *T. pulchra*, but with no shade cover. All exposure apparatuses were supplied by water reservoirs and plants were continuously watered by nylon strings during the field experiments. A total of six field experiments lasting 84 days each were performed with both species, from November 2009 to April 2011: 1. Nov 2009–Jan 2010 (spring-summer); 2. Feb–Apr 2010 (summer-autumn); 3. May–Jul 2010 (autumn-winter); 4. Aug–Oct 2010 (winter-spring); 5. Nov 2010–Jan 2011 (spring-summer); and 6. Feb–Apr 2011 (summer-autumn).

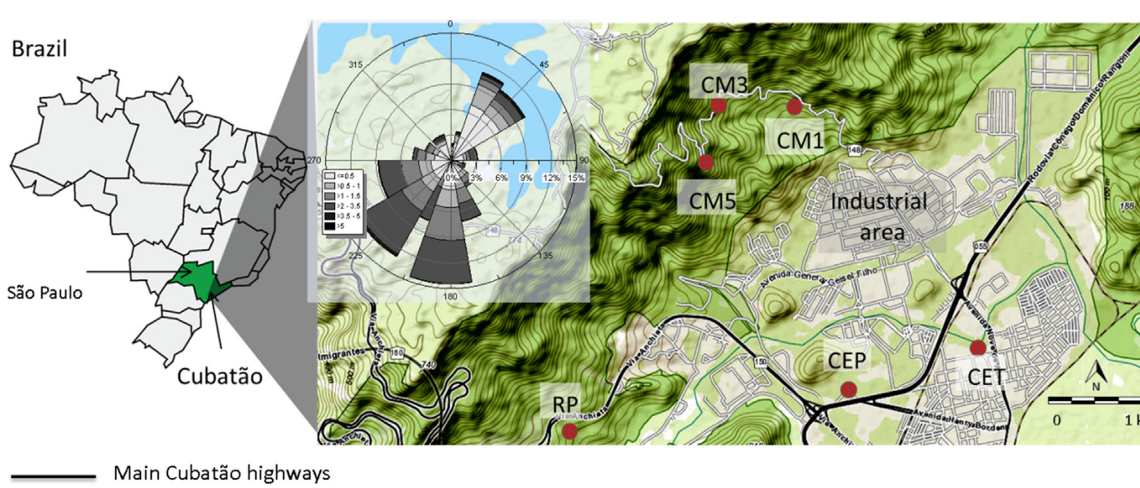

Fig. 1. Distribution of exposure sites around the industrial and urban areas of Cubatão, São Paulo-SE/Brazil (46°48′ W, 46°39′ W and 23°84′ S 23°90′ S). Data for construction of the wind rose were obtained from the air quality monitoring station installed at the CET site and were downloaded at www.cetesb.sp.org.br.