Ecological Indicators 60 (2016) 125–136

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Magnetic properties of *Tillandsia recurvata* L. and its use for biomonitoring a Mexican metropolitan area

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ARTICLE INFO

Article history:
Received 31 July 2014
Received in revised form 15 June 2015
Accepted 18 June 2015

Keywords:
Atmospheric pollution
Bioindicator
Magnetic properties
Monitoring
Magnetite

ABSTRACT

Some epiphytic species accumulate airborne particles and are suitable biological indicators for monitoring urban and industrial pollution. The species *Tillandsia recurvata* L. was studied as a monitor of air pollution in an urban area from Mexico. Individuals were collected in 25 sites which are exposed to different pollution degree and sources.

The magnetic particle concentration, particle size, and mineralogy were determined and compared with chemical contents for all samples. The highest values of magnetic concentration dependent parameters were observed in industrial and heavy traffic sites (e.g., mass specific magnetic susceptibility of up to $171.5 \times 10^{-8}\ m^3\ kg^{-1}$). In contrast, sites with low or without vehicular traffic reached low values (e.g., mass specific magnetic susceptibility of down to $1.8 \times 10^{-8}\ m^3\ kg^{-1}$). The integrated magnetic analysis (King's and Day's plots, remanent magnetization parameters and thermomagnetic measurements) revealed the presence of ferromagnetic minerals, mostly magnetite-like with fine grain sizes (0.1–1 μm) and subordinate presence of high-coercivity minerals. Selected samples were observed by SEM and EDS analysis and revealed the presence of Fe-rich particles, as well as trace elements, among others, As, Sb, S, Cr, Mo, V, Zn, Ba, Hg, Pt and Cu. Most of the elements detected by EDS were also quantified by ICP-MS measurements.

Multivariate statistical analyses prove a high correlation between magnetic parameters and elements, as well as allow us classifying sites in clusters (fuzzy c-means clustering) with different pollution degree. These results demonstrate the usefulness of the species *T. recurvata* L. as a passive pollution monitor, with an affordable and immediate application. This species is abundant not only in Mexico, but also in other cities from America.

1. Introduction

Magnetic monitoring is an appropriate technique to assess, as first approach, the influence of anthropogenic pollution in areas of interest (Petrovský and Elwood, 1999). In general, the atmospheric dusts in urban/industrial areas are collected using filters. This technique requires a strategic distribution of several devices in the area, which need to be maintained resulting in high cost and time investment. Environmental magnetism studies of dust collected by filters have been reported in European (Muxworthy et al., 2001; Sagnotti et al., 2006), Asian (Xie et al., 2001; Shu et al., 2001), and American (Castañeda-Miranda et al., 2014) cities.

In contrast, biological monitors are an advantageous alternative to monitor the air quality in urban areas. In particular, they do not need any special care and their collection time may vary between days to years according to the species used. Recently, several authors have demonstrated the capacity of some biomonitors (needles, tree leaves, tree ring cores, mosses and lichens) to suit as dust collectors, and they were used for magnetic monitoring of air quality (Lehndorff et al., 2006; Maher et al., 2008; Zhang et al., 2008; Jordanova et al., 2010; Fabian et al., 2011; Salo et al., 2012; Chaparro et al., 2013).

Tillandsia recurvata L. is an epiphytic plant of about 8 cm radius in average, which has a basic root system and usually has a spheroid shape (Madison, 1977). These plants have foliar trichomes that allow absorbing water, nutrients and dusts from the air (Rzedowski, 1981); they can colonize trees and cables and are available and well distributed in America, from the southern United States to the

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http://dx.doi.org/10.1016/j.ecolind.2015.06.025
1470-160X/

south Argentina and Chile (Correll and Johnston, 1970). The northernmost limit of its natural occurrence is coastal Georgia (where it is listed as a State "Special Concern" species), although it has been introduced into coastal South Carolina on landscaping trees. It has been reported in nature from Georgia, Florida, Louisiana, Texas, Arizona, Mexico, most of Central and South America, and many of the islands in the West Indies (Weakley, 2010). These characteristics and the distribution of the species allow studying its ability as collector of different pollutants, such as toxic elements, particulate matter (e.g., Shacklette and Connor, 1973; Schrimpff, 1984; Brighigna et al., 1997; Graciano et al., 2003; Fonseca et al., 2007; Goix et al., 2013) and magnetic oxides. Monitoring studies using transplanted individuals of *Tillandsia* spp. reported by different authors trace element accumulation for minimum time periods of 4 weeks (Pellegrini et al., 2014), as well as for 3–9 months (Bermudez et al., 2009; Abril et al., 2014).

In this study, the *T. recurvata* was investigated as collector of atmospheric dusts (magnetic particles and toxic elements) and its suitability for monitoring an urban area by measuring their magnetic properties. Among other available collectors in cities (e.g., urban soils, filters, river sediments, etc.), this biological species has diamagnetic properties at difference to industrial/urban pollutants (para, antiferro and ferrimagnetic properties). This fact makes it as an interesting recorder of magnetic pollutants. In addition, it is well-known that magnetic particles produced by pollution (industrial/urban) sources can act as host of heavy metals and other non-magnetic pollutants including them onto its crystalline structure or on its surface (e.g., Kukier et al., 2003; Chaparro et al., 2010). Therefore, magnetic measurements may be able to assess the adverse effects of anthropogenic activities over time. Our work is focused on the use of *T. recurvata* as an alternative bioindicator in cities, and to determine relevant parameters for magnetic monitoring. It is worth mentioning that the magnetic monitoring is a fast and low cost methodology applicable wherever the species can be recollected, and this way allows identifying contamination hotspots and critic areas for further complementary studies (e.g., Böhm et al., 1998; Moreno et al., 2003; Chaparro et al., 2013).

In particular, this work aims to investigate: (1) the potential use of *T. recurvata* as suitable dust collector, including magnetic particles; (2) the relationship between magnetic particles and chemical elements accumulated in this species; (3) the use of magnetic parameters measured in *Tillandsias* for spatial and temporal biomonitoring in urban areas.

2. Sampling and laboratory methods

2.1. Study area

Santiago de Querétaro (or Querétaro for short) city is the capital of Querétaro de Arteaga state from Mexico. It is located in the central Mexico volcanic highlands (20° 36′ N; 100° 24′ W) at about 1820 m a.s.l. (INEGI, 2006). The urban area covers about 741 km^2 and has ∼800,000 inhabitants but neighboring municipalities raise the population of the urban area to approximately one million (SEDESU, 2011).

The main sources of air pollution comprise vehicular traffic (automobiles and trucks), contributing about 75% of pollutants. For the city, registered vehicles reached 195,000 in 2010, with an annual growth rate of about 8% (INEGI, 2010). The higher abundance of Fe particles in the city center and the higher magnetic susceptibility values observed there suggest that vehicle emissions are an important source of pollution (Castañeda-Miranda et al., 2014). In addition, the industrial activities also contribute to air pollution according to Gasca (2007). Additional information is available in Supplementary data.

2.2. Sampling

About three individuals of *T. recurvata* were collected from 25 sites (a total of 70 samples) from the urban area and the outskirts, some of them with higher pollutant loadings, as well as influenced by different pollution sources (Fig. 1). For the sampling design, the city was subdivided into 25 squares of 4 km^2, including industrial, urban and outskirt areas. Within each square, a sampling point was chosen according to the availability of *Tillandsias*. Most of the sites are located along main streets and avenues where *T. recurvata* were often found on the *Prosopis laevigata* and *Acacia farnesiana* trees planted on the sidewalks (less common on *Shinus molle* and *Bursera fagaroides* trees). Both are endemic species and have a high relative abundance (25%) in Querétaro city (Castañeda-Miranda, 2015).

Samples were collected at a height of >1.5 m to avoid the influence of urban soil particles; moreover plastic scrapers and disposable gloves were used to avoid possible contamination with tools and between collection sites. As this plant is a composite of leaves of different ages, specimens of similar age were collected in order to avoid important differences in exposure periods, by choosing about 10–12 cm diameter size. All material was collected in March 2012, packed in paper bags and stored at room temperature in the laboratory before magnetic and other studies.

2.3. Magnetic measurements

Biological material was packed into nonmagnetic plastic containers (8 cm^3) and weighed (up to 3.2 g) for magnetic measurements. All rock-magnetic measurements were carried out in the Laboratory of Paleomagnetism and Rock-magnetism at Centro de Geociencias (UNAM).

A small amount of plant material (<50 mg) was used to measure magnetic hysteresis loops and remanent magnetizations in fields between −2 and 2 T at room temperature using a Princeton Measurement Corporation Micromag 2900 AGM system. Before the experiments, the material was dried and weighed to allow for calculation of mass-corrected hysteresis parameters. Among hysteresis parameters and ratios of interest, the saturation magnetization (M_s), saturation remanence (M_{rs}) and coercive force (H_c) were calculated. In addition, the high-field magnetic susceptibility (χ_{hf}) and the relative contribution of paramagnetic and diamagnetic minerals to the M_s (para/diamag. cont.) were calculated. From remanent measurements, IRM acquisition curves and the saturation of IRM (SIRM = IRM_{2T}) were determined using forward DC fields equally spaced on a logarithm scale. Remanent coercivity (H_{cr}), *S*-ratio (=$-IRM_{-300mT}$/SIRM), ARM/SIRM and SIRM/κ ratio were also calculated.

Selected samples (of about 100–220 mg) were studied in a laboratory built horizontal magnetic balance to produce thermomagnetic curves. The induced field was chosen at 0.5 T, and ramp-rates during heating and cooling were 30 °C min^{-1}. Samples were heated in air to a temperature of about 700 °C and subsequently cooled to room temperature (RT). The relative values of induced magnetization (M/M_{RT}) are of interest in this study; hence the $M/M_{RT} - T$ curves are presented.

Measurements of low-field magnetic susceptibility, volumetric (κ) and mass-specific (χ), were carried out using a KLY-3 meter (AGICO). Also, the frequency-dependence of magnetic susceptibility κ_{FD}% ($\kappa_{FD}\% = 100 \times [\kappa_{0.47} - \kappa_{4.7}]/\kappa_{0.47}$) was computed from measurements with a MS2 (Bartington Instruments Ltd.) instrument linked to the MS2B dual frequency sensor (0.47 and 4.7 kHz).

Anhysteretic remanent magnetization (ARM) was imparted using a laboratory built alternating field (AF) demagnetizer by superimposing a DC bias field of 90 μT to an alternating magnetic field of 100 mT amplitude, and the ARM was measured with an induction magnetometer (JR-5, AGICO). Anhysteretic susceptibility