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Original Articles

Changes in epiphytic lichen diversity are associated with air particulate matter levels: The case study of urban areas in Chile

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ABSTRACT

Chileans living in urban areas are exposed to several air pollutants, namely to a mean annual concentration of atmospheric $PM_{2.5}$ (> 40 μg m^{-3} year^{-1}) that exceeds two times the level established by legislation in both Chile and the European Union and four times higher than the recommended by the World Health Organization for good air quality. The evaluation of air pollution, namely particulate pollution, in urban areas is performed by air quality monitoring stations. These, are not sufficiently distributed in space to cover all areas with high spatial resolution, needed for a good assessment of the exact human exposure. In this context, lichen diversity studies could fill the gap of increasing air quality spatial resolution in areas not covered by monitoring stations. We aim at using taxonomic (species richness and abundance) and trait-based epiphytic lichen diversity (growth form) to evaluate the impact of air pollution levels in Chilean urban environments. For that, lichen diversity was evaluated in three background areas, seven centres of various Chilean cities and their peri-urban zones. Though trait-based metrics responded negatively to air pollution, lichen abundance was the best metrics (index of lichen diversity), being negatively associated ($r = -0.89$; $p < 0.001$) with the number of days per year that particles exceeded the mean annual level established by legislation (> 20 μg m^{-3} year^{-1}). This suggested that the main source of changes in lichen diversity in urban areas of Chile is particulate material or other associated pollutants. These findings show that in high levels of pollution, total lichen diversity can be used to track particulate material pollution above the recommended levels, providing data for areas without monitoring stations. This information can then be used to select new areas for monitoring stations, or to evaluate the potential health effects of the population living in these areas.

1. Introduction

Exposure to pollutants such as airborne participate matter (PM) has been associated with increases in mortality and hospital admissions due to respiratory and cardiovascular disease (World Health Organization (WHO), 2016). These effects were found in short-term studies relating day-to-day variations in air pollution and health, and long-term studies following cohorts of exposed individuals over time. Effects of air pollution have been seen at very low levels of exposure. It is unclear whether a threshold concentration exists for PM which no effects on health are likely (Brunekreef and Holgate, 2002).

Air pollution is worsening in urban areas much across the globe, hitting the poorest city dwellers harder, and contributing to a wide range of potentially life-shortening health problems, from heart disease to severe asthma (WHO, 2016). The presence of PM in urban environments is directly related to anthropogenic factors, including industrial activities, traffic, movement of people, poorly ventilated spaces, and urban microclimate (Querol et al., 2001). PM with aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$) are very hazardous for human health because they can reach bronchioles and alveolar ducts and move from there to other parts of the body, causing cardiovascular and pulmonary diseases and even death (*e.g.* Dockery and Pope 1996; Analitis et al., 2006; Landrigan et al., 2017).

Lichens have been used for decades as biomonitors and ecological indicators because of their sensitivity to diverse atmospheric pollutants such as NH_3, NO, SO_2 and heavy metals (see *e.g.* Martin et al., 1982;

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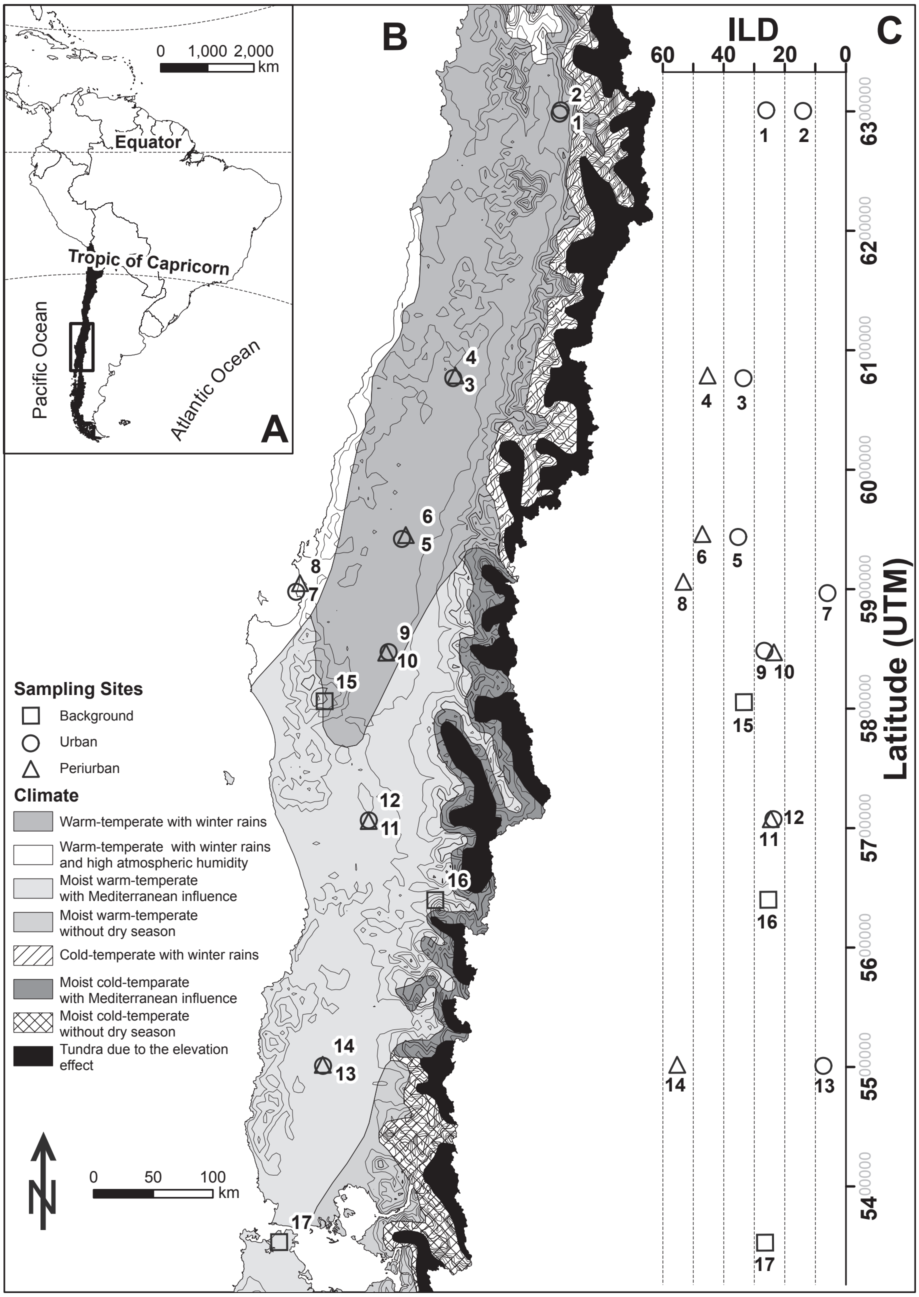

Fig. 1. A) Map showing the study area in the southern hemisphere. B) Location of the 17 sampling units (background: □, urban: △ and periurban: ○) in the study area, the different climates (according to Albers 2012) and contour lines every 500 m. C) Relationship between the Index of Lichen Diversity values (ILDs) and Latitude (UTM).

Galun and Ronen, 1988; Nimis, 1991; Van Dobben and De Bakker, 1996; Nimis and Purvis, 2002; Augusto et al., 2013) to atmospheric disturbances such as eutrophication and climate change (*e.g.* Frati et al., 2006; Pinho et al., 2012; Branquinho et al., 2015; Matos et al., 2015). Analysis of lichen diversity has been successfully used to monitor the effects of atmospheric pollution in urban environments (*e.g.* Munzi et al., 2007, 2014; Davies et al., 2007; Pinho et al., 2008; Käffer et al., 2011; Llop et al. 2012, 2017; Koch et al., 2016; Vieira et al., 2018) and the effects of particles in traffic-exposed areas (Madl et al., 2010). Biomonitoring with lichens can be carried out in several different ways: i) by determining total or functional diversity metrics (Asta et al., 2002; Pinho et al., 2009, 2011; Matos et al., 2015; Vieira et al., 2018; Schleuter et al., 2010), ii) by measuring physiological parameters in lichens (Munzi et al., 2014); and iii) by considering lichens as bioaccumulators of pollutants (Branquinho, 2001). According to Branquinho et al. (in press) to decide what is the best biodiversity-based metrics we need to understand the intensity of the driver that is mainly limiting or affecting biodiversity. A lower intensity of the impacting driver will likely affect organism's individual performance, measurable through ecophysiology-based metrics; a medium intensity of the driver may affect the ecological performance of sensitive species before tolerant ones, leading to changes in species abundance and consequently to changes in community functional characteristics, reflected by trait-based metrics. A higher intensity of the driver may culminate in most species loss, reflected by taxonomic-based metrics.

Most studies dealing with urban air pollution with focus on PM are developed in Northern hemisphere and only few are devoted to South America (Lelieveld et al., 2015). Although studies using lichens as ecological indicators are widely spread around the world, those using trait-based metrics, are still poorly studied, particularly in urban areas