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# Floristic changes of epiphytic flora in the Metropolitan Lisbon area between 1980–1981 and 2010–2011 related to urban air quality

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ABSTRACT

Epiphytic lichen and bryophyte Floristic Richness (FR) and distribution were investigated in Lisbon and the adjacent southern riverbank, in the centre-west of Portugal within the Lisbon Metropolitan Area (LMA). Field studies were carried out in the years 2010–2011 to replicate research conducted 30 years ago in 1980–1981.

Compared to previous surveys, we confirm that the overall environmental condition has largely improved, with higher epiphyte richness. The two areas have been recolonized during the last 30 years by sensitive species mainly due to changes in $SO_2$ levels. However, the traffic-related $NO_2$ and dust deposition have become the main pollutants and the increase of nitrophilous and saxicolous/terricolous *taxa* reflects this influence. But, besides air pollution, the important variable affecting the epiphytic flora of LMA, currently updated to more than 200 *taxa*, is the influence of arborisation system type, road type and road proximity of the new surveys, in addition to urbanization (calculated in an Index of Human Impact – IHI).

According to their current epiphyte diversity, with Floristic Richness (RF) ranging from 4 to more than 90 taxa (lichens and bryophytes), five zones were identified in LMA and related with air quality.

As a conclusion, significant changes in the Floristic Richness (FR) were observed over the past 30 years, not only the value but also the spatial pattern which differs greatly between the two areas, linked significantly with air quality and other human influences.

Due to the few number of available air quality monitoring stations, in particularly for $NO_2$ values, the important contributions of epiphytic flora in defining the distribution range and spatial patterns of urban disturbance imply that FR may be a practical and useful indicator of air quality in LMA.



## 1. Introduction

It has long been accepted that lichens and bryophytes are reliable indicators, especially those of epiphytic assemblages which are strongly linked to diverse environmental factors such as habitat variability and quality, water availability, light intensity, bark properties, tree disease, as well as air quality (Barkman, 1958; Smith, 1982; Bates, 2002; Gerdol et al., 2014; Ellis et al., 2014). Recently, the multiple forms of nitro-phytotoxic effect on lichens or bryophytes have been well documented (Van Herk, 2001; Leith et al., 2008; Jovan et al., 2012; Boltersdorf et al., 2014), inducing the nitrophytic species that are normally associated with eutrophication or hyper-trophication (Seaward and Coppins, 2004; Davies et al., 2007). On the other hand, air properties such as dust deposition rates may also play a significant role in lichen and bryophyte disturbance (Van Haluwyn and van Herk, 2002; Fudali, 2006; Agnan et al., 2014).

In most of the polluted European regions, during the last three decades, the epiphyte flora has expressed another modification: many authors noted the return and the proliferation of species sensitive to $SO_2$ air pollution, not only in urban areas (Greven, 1992; Bates et al., 1997; Davies et al., 2007; Blockeel et al., 2014) but also in industrialized regions, such as in Portuguese industrial areas (Sim-Sim et al., 2000; Carvalho et al., 2002a,b).

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Generally, the majority of species sensitive or with moderated resistance to $SO_2$ are now much more abundant and disseminated, and consequently a tendency in the homogenization of epiphytic vegetation in humanized areas has been recognized (Sim-Sim et al., 2000; Liška and Herben, 2008; Evju and Bruteig, 2013).

Over the last decades, levels of sulphur deposition from air pollution have substantially reduced in Portugal (Ferreira et al., 2002) as well as in particular urban areas such as Lisbon, whereas levels of nitrogen deposition have somewhat increased, as experienced elsewhere in the Mediterranean, Europe and even globally (Ochoa-Hueso et al., 2011; Pinho et al., 2012, 2014). At the moment nitrogen deposition is a major reason for biodiversity change in terrestrial ecosystems (Bobbink et al., 2010; Van den Berg et al., 2011). Nevertheless, some lichen species respond positively to nitrogen pollution (Larsen et al., 2007; Munzi et al., 2014a,b) and in a long-term ecological study in London rapid changes in lichen and bryophyte diversity were observed, caused mainly by reduced pollutants, as well as others socio-economic factors (Purvis et al., 2010).

The aim of this work is to evaluate recent changes in the epiphytic diversity based on a baseline assessment carried out in 1980–1981 (Sérgio, 1981; Bento-Pereira and Sérgio, 1983; Sérgio and Sim-Sim, 1985) by this research group at Lisbon University. Using the results of a new biomonitoring survey (2010–2011) in the same region, we aim also to have updated air quality measurements by analysing the cryptogamic composition of the epiphytic assemblages. On the other hand this work is also in the wake of research carried out in Portugal that have monitored the temporal changes of epiphytic vegetation of both lichens as bryophytes.

So, the main objectives of this study are to identify changes over a 30-year period as well as obtain a new baseline for epiphyte biodiversity. This new data will be also important for validation of expected scenarios as a consequence of anticipated climate changes (Ellis et al., 2007; Sérgio et al., 2011; Evju and Bruteig, 2013).

As specific objectives, we can highlight: (1) to survey the diversity of epiphytic lichens and bryophytes in the region (compared wherever possible at the same location previously carried out, either in urban, industrial and peri-urban areas); (2) reveal trends in epiphyte distributions in time especially in the species found in the two investigated period; (3) to estimate the changes in floristic composition linked to air quality, to identify the main underlying causes associated with other human influences using an Index of Human Impact (IHI).

## 2. Methods

### 2.1. Study area characterization

The study area (Figs. 1 and 2) is within the Lisbon Metropolitan Area (LMA), located on the banks of the Tagus estuary, western coast of Portugal. It occupies a total surface area of *ca.* 700 $km^2$, and includes Lisbon (northern bank, *ca.* 85 $km^2$) and the Setúbal Peninsula (southern bank), comprised of 8 municipalities (Almada, Seixal, Barreiro, Montijo, Moita, Alcochete, Palmela and Setúbal). There are more than 600 000 inhabitants in Lisbon and 700 000 inhabitants in the Setúbal Peninsula (INE, 2011). Lisbon is the largest city in Portugal and LMA is one of the most populated regions of the country, with a population density varying from more than 6000 people/$km^2$ in the city to less than 150 people/$km^2$ in Montijo, Alcochete and Palmela municipalities. The area with highest population density in the Setúbal Peninsula is located close to the river (Fig. 2B).

The topography of Lisbon areas is highly heterogeneous, contrasting with the more or less flat area extending from the Tagus River to the border of the Arrábida mountain range. The coast of the Setúbal Peninsula corresponds to a vast, almost flat area, westwards limited by Costa da Caparica and southwards by the Espichel Cape and the Arrábida Mountain. The development of some new urban centres in the Setúbal Peninsula is closely connected to the territorial processes in LMA (Campo, 2009). In the study area, the altitude of the urbanized parts is below 160 m; however, west of Lisbon, the Monsanto hill (a wooded area) reaches 226 m.

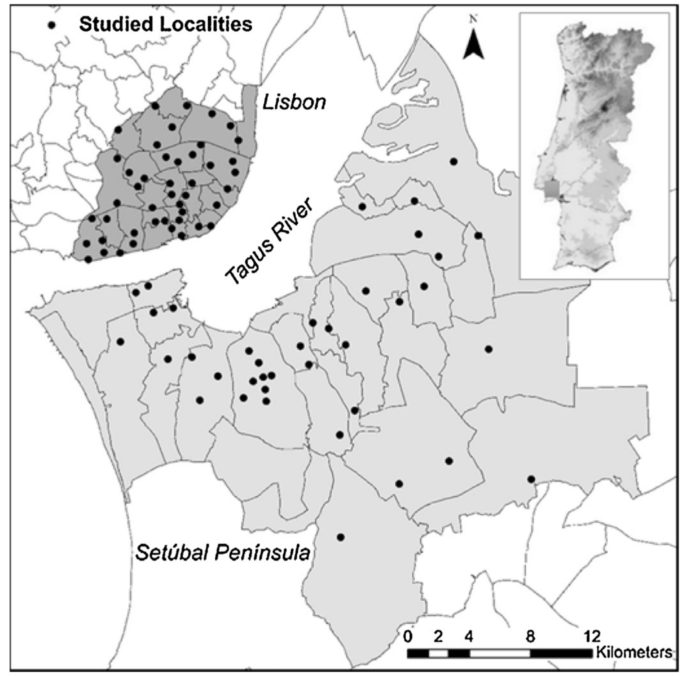


**Fig. 1.** Sampling sites in Lisbon and Setúbal Peninsula (southern bank of the Tagus River). Boundaries represent different municipalities. For pollutant monitoring stations including the values, see Figs. 7 and 8. For list of study locality names and numbers see Appendix A1.

The climate is Mediterranean and three main aspects control the urban environment: the vicinity of the Atlantic Ocean to the west and southwest, the large estuarine area (Tagus River) and the complex topography. The climate also depends on relief, especially in the Setúbal area, and the influence of altitude is greater in winter than in summer (Alcoforado and Andrade, 2006; Alcoforado et al., 2009). The average annual precipitation is 650–760 mm, with a maximum during the winter months (December to February) and minimum in July and August. The wind regime and local weather affect the spatial pattern of temperatures in the area. During summer, the wind regime in Lisbon is dominated by a relatively strong northerly wind, typical of western coast of the Iberian Peninsula, the "Nortada". Although the latitudinal variation is irrelevant in the region, there is some dissimilarity between the two river banks, evident in the general ombrotype models. In Lisbon, the Ombrothermic Index is "sub humid", and the Setúbal Peninsula corresponds to the "upper dry" level (Mesquita and Sousa, 2009).

The environment in the whole region is influenced by the urban layout, as well as by traffic on major highways and roads of regional importance. Although strong industrial pollution sources are not particularly present in Lisbon, this region is one of the most polluted Portuguese urban areas due to traffic (Ferreira et al., 2002). The inventory of $NO_X$ emissions, measured in the Lisbon area during 2001 and 2002, indicates that the road transport sector is responsible for more than 75% of the total emissions in the region (Góis et al., 2007; Mesquita, 2009). However, the significant proportion of urban trees in relation to city population provides important services, valued by the large number of residents and people commuting to and from Lisbon every day (Soares et al., 2011).