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Response of exposed bark and exposed lichen to an urban area

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Summary. The aim of this study is to understand emission sources of chemical elements using biomonitoring as a tool. The selected lichen and bark were respectively *Parmotrema bangii* and *Criptomeria japonica*, sampled in the pollution-free atmosphere of Azores (Sao Miguel island), Portugal, and were exposed in the courtyards of 22 basic schools of Lisbon. The exposure was from January to May 2008 and from June to October 2008 (designated through the text as winter and summer respectively). The chemical element concentrations were determined by INAA. Conductivity of the lichen samples was measured. Factor analysis (MCTTFA) was applied to winter/summer bark/lichen exposed datasets. Arsenic emission sources, soil with anthropogenic contamination, a Se source, traffic, industry, and a sea contribution, were identified. In lichens, a physiological source based on the conductivity values was found. The spatial study showed contribution of sources to specific school positioning. Conductivity values were high in summer in locations as international Lisbon airport and downtown. Lisbon is spatially influenced by marine air mass transportation. It is concluded that one air sampler in Lisbon might be enough to define the emission sources under which they are influenced.

1. Introduction

Biomonitoring studies using lichens to measure their pollutant-specific response are commonly used to indicate geographical variances in trace-element air pollution because they depend mainly on the input of the atmospheric mineral nutrients [1]. Lichens could be advantageously used to apportion the distribution of element concentrations in big areas [2]. A key lichen parameter is the lichen physiological vitality, sometimes analyzed by determination of the lichen membrane permeability. Although there are several experimental procedures to test the impact of environmental pollution on lichen vitality, measuring either the conductivity or the K^+ content of a leachate with an appropriate electrode is the easiest way of monitoring the membrane integrity [3]. Electric conductivity of lichen was pointed out as the most sensitive parameter of its physiological response to environmental stress, when compared to the normalized difference vegetation index and chlorophyll degradation. Bark has equally been used as biomonitor and a few publications confirm its good performance when compared to lichens [4–6].

The presence of chemical elements in biomonitors may depend on several inputs, namely from local and long-range air pollution, natural cycling processes (airborne sea-salt, volcanic sources, biogenic emissions from marine and terrestrial environments), throughfall/stemflow leaching from vascular plants into epiphytic organisms, and mineral particles, mainly wind-blown soil dusts [7–10].

Epiphytic *Parmotrema bangii* was used in this study because it is an adequate choice for further lichen-based concentration patterns [8, 11, 12]. *Cryptomeria japonica*, the tree from where *Parmotrema bangii* was collected, is also an alternative to epiphytic lichens for air-monitoring purposes as concluded in previous studies [7, 13, 14]. Using these two biomonitors we aim to get answers to the following questions: 1) how conductivity can be a measure of pollution through Lisbon city when compared to the elemental concentrations, 2) how bark compare with lichen, 3) which sources are visualized by the biomonitors, 4) how representative is a unique air sampler in Lisbon.

2. Methodology

Samples of the lichen species *Parmotrema bangii* were collected from *Criptomeria japonica* trunks (Japanese cedar trees) in São Miguel, in the Azores islands (37°47′25.6″ N; 25°38′12.8″ W; elevation: 261 m), in January and May 2008. All lichen and bark samples collected in January, and more than 50% of those collected in May, were from the same tree; these samples are designated in this study by unexposed lichen samples and unexposed bark samples, respectively. The periods between sampling in the Azores and exposure in Lisbon were 2 and 3 weeks, in winter and summer campaigns respectively.

On arrival from Azores, the samples were distributed in 98 pieces of bark with the lichen over them. Ten of these pieces were kept in the laboratory, unexposed to Lisbon air

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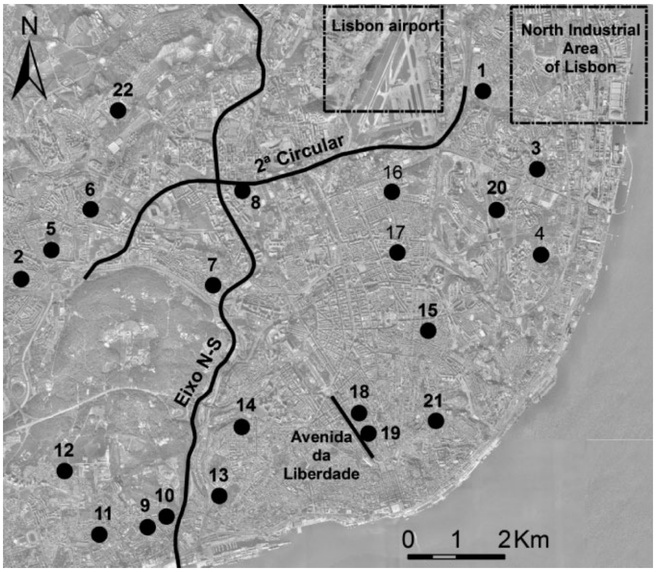

Fig. 1. Localization of the Lisbon schools where bark and lichens were exposed in winter and in summer campaigns.

pollution to estimate the baseline of lichen and bark samples, and they were immediately processed as explained below. The other pieces were exposed to Lisbon air pollution by suspending them with a nylon string from the trees of the courtyards of 22 elementary school in Lisbon (Fig. 1), four replicates in each courtyard, in a total of 88 pieces. The pieces were exposed from January to May 2008 (designated by winter or winter campaign) and from June to October 2008 (designated by summer or summer campaign), because it is known from other publications that air pollutants may be different and may have different sources in the considered periods [15, 16]. At the end of the winter campaign, 41 lichen samples and 38 bark samples could be recovered from 14 schools; at the end of the summer campaign, 66 lichen samples and 60 bark samples could be recovered from 20 schools.

The unexposed and exposed lichens were separated from the respective barks; both were cleaned from dust, leaf debris, fungus contamination and degraded material. Then they were rinsed three times for 5 s, in 18 MΩ water [17, 18], freeze-dried, and ground by vibration inside PTFE capsules under liquid nitrogen. Pellets of around 250 mg were prepared.

The chemical content was determined by Instrumental Neutron Activation Analysis (INAA). The pellets were irradiated during 5 h in the Portuguese Research Reactor (RPI) at a thermal neutron flux of about 3×10^{12} cm^{-2} s^{-1}. Gamma-spectra of the irradiated samples were acquired with high-resolution hyperpure germanium detectors, after 4 d and 4 weeks. A comparator – an Al-0.1%Au disc – was irradiated together with the samples and measured for application of the k_0-INAA methodology [19, 20]. More details of the analytical procedure may be found elsewhere [4, 5, 7, 11].

Quality control was asserted by analyzing 9 subsamples of the certified reference material IAEA-336 lichen following similar procedures to the ones described for the bark and lichen samples.

The electric conductivity was measured in unexposed and exposed lichens. The electric conductivity of the 18 MΩ water was measured before each lichen conductivity measurement – blank value. Lichen samples of about 100 mg, 24 h air dried material, were immersed in 10 ml 18 MΩ water for 60 min following the procedure described in [17], and the conductivity was measured with an electric conductivity meter (*Mettler Toledo*). All results were subtracted from the blank values.

Meteorological data during the exposure periods were $73.4 \pm 15.1\%$ (humidity) and 14.0 ± 3.2 °C (temperature) for the winter campaign and $66.9 \pm 16.3\%$ (humidity) and 20.2 ± 3.5 °C (temperature) for the summer campaign. The temperature and the humidity values of the two campaigns are significantly different at 95% confidence level ($P = 0.000$).

3. Results and discussion

The mean of the conductivity values obtained in the 10 unexposed samples was 0.14 ± 0.12 mSm^{-1} g^{-1} and 0.28 ± 0.11 mSm^{-1} g^{-1} in winter and summer respectively. These values were of the order of magnitude of the ones obtained elsewhere [17] in *Flavoparmelia caperata* collected at Tomar region (mainland Portugal), considered an unpolluted area. The lichen conductivity mean values were higher during the summer than during the winter, as might be expected because of the warmth in summer [1, 21]. However, the difference was not statistically significant at 95% confidence level (P=0.203). Therefore, it may be considered that the lichen vitality at the start of both campaigns was identical. The conductivity mean values after exposure were 0.071 ± 0.025 mSm^{-1} g^{-1} and 0.32 ± 0.17 mSm^{-1} g^{-1}, in winter and summer respectively. The means were considered statistically different ($P = 0.000$), meaning that the lichen vitality was influenced by the exposure as concluded before by other authors [17, 21].

Fig. 2 shows the ratio of the mean values obtained in this work for the reference material IAEA-336 lichen and its cer-

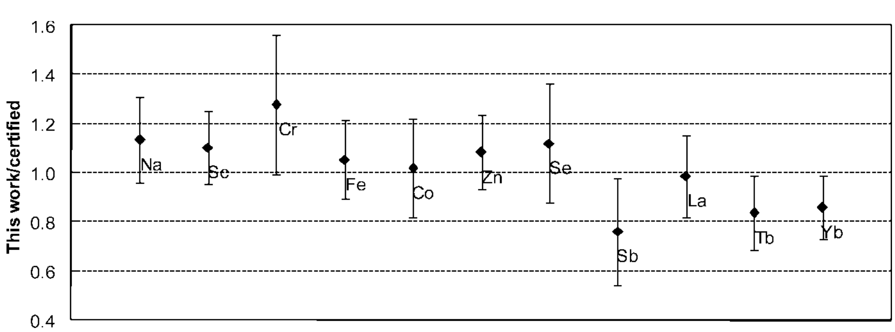

Fig. 2. Ratio between the mean of 9 replicates obtained in this work for IAEA-336 lichen reference material and its reported certified values. Ratio uncertainties include both the ones of the mean values and the certified values, and are at 95% confidence level. No informative or certified value is reported for Hf.

Table 1. Chemical element's mean concentration and standard deviation in unexposed and exposed (all schools as a set) bark and lichen samples, calculated for winter and summer campaigns. Statistical differentiation between summer and winter is presented by the *P* value, obtained using an unpaired Student's *t*-test. Significant different concentrations at 95% confidence level are given in bold.

	Bark					Lichen				
	Winter		Summer			Winter		Summer		
Element	Aver.	St. Dev.	Aver.	St. Dev.	*P* value	Aver.	St. Dev.	Aver.	St. Dev.	*P* value
Unexposed										
Na	800	100	1086	31	**0.009**	1678	84	1310	110	**0.010**
Sc	0.040	0.008	0.067	0.002	**0.006**	0.37	0.02	0.19	0.16	0.132
Cr	0.40	0.07	0.50	0.08	0.186	6.0	0.4	3.0	1.2	**0.016**
Fe	279	178	333	15	0.630	1089	54	642	562	0.243
Co	0.05	0.04	0.125	0.007	**0.038**	0.34	0.02	0.27	0.07	0.204
Zn	3.8	1.4	5.22	0.48	0.177	21.7	1.7	13	12	0.286
Se	0.15	0.04	0.107	0.008	0.166	–	–	0.4	0.1	–
Sb	0.04	0.04	0.067	0.004	0.351	0.08	0.03	0.03	0.03	0.067
La	0.64	0.18	0.79	0.04	0.232	2.7	0.1	1.8	0.2	**0.002**
Hf	0.021	0.008	0.043	0.003	**0.010**	0.38	0.05	0.20	0.01	**0.004**
Tb	0.0100	0.0009	0.009	0.001	0.514	–	–	–	–	–
Yb	0.014	0.002	0.020	0.003	0.067	–	–	–	–	–
Exposed										
Na	831	147	840	183	0.946	1100	231	941	208	0.720
Sc	0.14	0.06	0.2	0.1	0.359	0.42	0.09	0.38	0.08	0.872
Cr	1.4	0.6	2.1	1.1	**0.030**	5.3	2.1	3.8	0.8	**0.048**
Fe	741	322	1020	536	0.342	1590	322	1490	260	0.875
Co	0.26	0.09	0.3	0.1	0.675	0.49	0.09	0.46	0.07	0.398
Zn	13.1	5.4	15.5	4.7	0.548	45	10	39.0	4.4	0.060
Se	0.35	0.15	0.4	0.1	0.752	0.65	0.12	0.62	0.09	0.613
Sb	0.20	0.08	0.21	0.07	0.834	0.28	0.08	0.19	0.04	**0.031**
La	1.5	0.6	1.7	0.7	0.480	2.1	0.4	2.2	0.4	0.526
Hf	0.09	0.03	0.14	0.10	0.128	0.30	0.06	0.27	0.06	0.712
Tb	0.02	0.01	0.02	0.01	0.962	0.03	0.01	0.03	0.01	0.544
Yb	0.04	0.02	0.05	0.02	0.627	0.08	0.02	0.07	0.02	0.832

tified values. Results are within ±22% of agreement with the certified values. Taking into account the uncertainties, all values are in good agreement, therefore the quality of the analytical procedure was assured.

Table 1 shows the mean and its standard deviation of selected chemical elements determined by INAA in unexposed samples, and exposed samples in both campaigns. To check whether there are significant differences in the element concentrations between the campaigns, an unpaired Student's *t*-test (independent samples) was conducted and the results are shown in Table 1, as well.

In unexposed lichens, the ones coming from Azores island, statistically significant differences (95%) were found between the concentrations of Cr, Hf, La, and Na, obtained in summer and winter. These elements are usually soil-related; Na is also a marine component when there is close proximity of oceans [22, 23] which is the case. For all of them, the concentrations were higher in winter than summer, meaning larger uptake during winter. According to other publications [15, 16], the soil resuspension by traffic is higher in winter than summer. Furthermore, larger entrances of sea spray are observed during winter as compared to summer [11, 16]. Se, Tb, and Yb in the unexposed bark samples were below the detection limit of INAA. Statistically significant differences (95%) of elements concentrations between summer and winter were found for Co, Hf, Na, Sc. The concentrations of Co and Sc were higher in summer than in winter, while the one of Hf was higher in winter than in summer (similar result to unexposed lichen); the Na concentrations in lichen were higher in summer than in winter while in bark it was the other way around. The different behavior towards soil and sea-spray related elements indicates that the differences at the start of exposure, either for lichen or bark, must be taken into account in the discussion of the results of exposed samples. All the other elements were not statistically different in the two sampling periods.

Table 2 shows the mean and standard deviation for the same set of chemical elements in exposed lichen and exposed bark during the campaigns. The latter showed significant differences (95%) between summer and winter for Cr with higher concentrations during summer. Since this element presented statistically identical values at exposure start, it may be concluded that Cr was uptaken in both winter and summer, and more during the latter – it is concluded that one Cr source influences Lisbon the whole year although with higher intensity during summer. The elements Co, Hf, Na, Sc whose concentrations in bark were different at the start, turned out equal at the end of the exposures. It is then concluded that these elements are in sources which influence Lisbon. As for the lichen samples, there were statistically significant differences (95%) between summer and winter campaigns in the concentrations of Cr and Sb, with lower levels during summer. A conclusion that can be taken here is that Cr is an element for which bark and lichen respond differently, since the Cr uptake in bark was higher in summer while in lichen was lower. Concerning Sb, related to traf-

Table 2. Mean values contributions (%) of the factors (obtained by MCTTFA) to total element occurrence calculated for bark and lichen in both campaigns. Elements with significant positive loadings are marked: + means 95% < *P* < 99%, ∗ means *P* > 99%. The most significant element (the pilot element) in a factor is marked with *P*.

	Bark						Lichen					
	Factor 1	Factor 2	Factor 3	Factor 4	Total		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Total
Na	0.03^{*}	0.00	***0.04***$^{+}$	0.32P	0.39	Na	0.55^{*}	0.01	0.00	0.02	0.41P	0.98
Sc	0.28^{*}	0.25^{*}	***0.32****	0.32^{*}	1.17	Sc	0.97^{*}	0.04^{*}	0.00	0.02^{+}	0.10^{*}	1.13
Cr	0.27^{*}	0.29^{*}	0.00	0.00	0.56	Cr	0.61^{*}	0.51P	0.00	0.09^{+}	0.01	1.22
Fe	0.25^{*}	0.30^{*}	0.34^{*}	0.23^{*}	1.12	Fe	0.88P	0.03^{*}	0.00	0.05^{*}	0.05^{*}	1.01
Co	0.13^{*}	0.48^{*}	0.08^{*}	0.22^{*}	0.91	Co	0.58^{*}	0.00	0.00	0.16^{*}	0.01	0.75
Zn	0.00	0.84P	0.00	0.04	0.89	Zn	0.03	0.23^{*}	0.00	0.00	0.05^{+}	0.31
Se	0.08^{*}	0.00	0.54P	0.25^{*}	0.87	Se	0.55^{*}	0.00	0.00	0.03^{+}	0.01	0.59
Sb	0.06^{*}	0.59^{*}	0.31^{*}	0.00	0.97	Sb	0.00	0.21^{*}	0.00	0.74P	0.11^{+}	1.05
La	0.17^{*}	0.13^{*}	0.36^{*}	0.08^{*}	0.75	La	0.75^{*}	0.00	0.00	0.05^{*}	0.00	0.80
Hf	0.33P	0.38^{*}	0.14^{*}	0.41^{*}	1.26	Hf	1.03^{*}	0.05^{*}	0.00	0.00	0.13^{*}	1.21
						Conductivity	0.00	0.00	1.00P	0.00	0.00	1.00

fic in Lisbon [15, 23, 24], it is expected that values are lower in summer because the traffic is drastically reduced due to the end of the school year (most of the parents use private cars as transport just because they need to take their children to school, otherwise they use public transportation) and the commuter summer vacation period [15].

For lichen, ratios between mean values in winter and summer were higher than unity (winter > summer) for Co, Cr, Fe, Hf, Na, Sb, Sc, Se, Tb, Yb, Zn. For bark, ratios larger than unity were not found in any of the elements, this is, most of the elements showed higher concentrations in summer.

When the ratios (exposed/unexposed) are considered, a P z-score test applied to lichen results showed that statistically significant differences (95%) were found for Na (< 1), Sb and Zn (both > 1) in winter, and Co, Fe, Sb, Sc, Se, Zn (all > 1) in summer. This means that 1) the lichen samples lost Na which is understandable because they came from a more enriched Na environment (one small island in the middle of North Atlantic Ocean); this release after accumulation was also observed elsewhere [25] in an experiment where lichens were exposed to a polluted area and later to an unpolluted environment, 2) they uptook Sb and Zn from vehicles tiers wear out, 3) they uptook Co, Fe, Sc from soil particles and soil resuspension, and 4) uptook Sb, Se, Zn from industrial areas [26–28]. If the ratios (exposed/unexposed) in winter and summer are compared (P *t*-test, 95%), only Fe, Sb, and Sc (all higher in summer than winter) are statistically different, maybe indicating Sahara dust [16].

For bark, statistically significant differences (P *z*-score test, 95%) between exposed and unexposed means were found for Co, Hf, Sb (all > 1) in winter, and Sb, Se, and Zn (all > 1) in summer. When summer and winter campaigns are compared, statistically significant differences (P *t*-test. 95%) were not found for any of the elements. Different responses of bark and lichen are therefore obtained, when the mean of the values is considered. Similar differences were pointed out previously [28–30].

To check whether there is a significant relationship between the elemental concentrations in exposed bark and lichen, Pearson correlations were calculated for both campaigns (not shown). Positive and statistically significant correlations (95%) between the elemental concentrations of exposed lichen and exposed bark were found during winter for Fe ($r = 0.61$, $p = 0.034$), La ($r = 0.76$, $p = 0.004$), Na ($r = 0.58$, $p = 0.048$), and Yb ($r = 0.74$, $p = 0.006$) – all might be considered natural source related (marine and soil), and no correlations were observed with the summer data.

Pearson correlations were also calculated between conductivity determined in exposed lichen and its elemental concentrations. Only Tb ($r = -0.56$, $p = 0.037$) and Yb ($r = -0.56$, $p = 0.040$) determined in winter showed statistically significant correlations (95%). No explanation was found for the selective preference to these two elements.

Factor analysis Monte Carlo Target Transformed Factor Analysis, (MCTTFA) was applied to winter and summer bark and lichen exposed datasets. The most significant element (the pilot element) in a factor is marked with P. MCTTFA [31, 32] approach consists of: (1) the data set is first transformed into standardized variables which are assumed to be a linear sum of factors (emission sources); (2) a unique contribution, specific for each individual sampling site is calculated depending of coefficients designated by loadings of the factors, representing the correlation of elements with factors, and of coefficients symbolizing the contribution of factors to samples; (3) the target transformation is an iterative method to satisfy the condition that the loadings should not contain negative values; (4) the uncertainties in the obtained loadings are estimated using a Monte Carlo approach. In order to choose the optimal number of factors for both bark and lichen, use was made of the number of factor identification conflicts (FIC) [31, 32]. In case of bark an increase of FIC can be observed at 5 factors (data not shown). For lichen the FIC show a sharp rise at 6 factors. Therefore respectively 4 and 5 factors were chosen as the optimal number of factors to be used.

The mean values contributions (%) to total element occurrence calculated for bark and lichen on both campaigns are presented in Table 2. With the bark dataset, 4 factors were obtained. Soil with some anthropogenic contamination (Co, Cr, Fe, Hf – pilot element, Na, La, Sb, Sc, Se) was identified by Factor 1. Factor 2 indicates an anthropogenic source with Zn as pilot element, Sb, Co, and also soil-related Cr, Fe, Hf, La, Sc. These elements are associated with different sources namely coal combustion, cement production, incineration [22] and traffic (mainly tires and brakes' wear

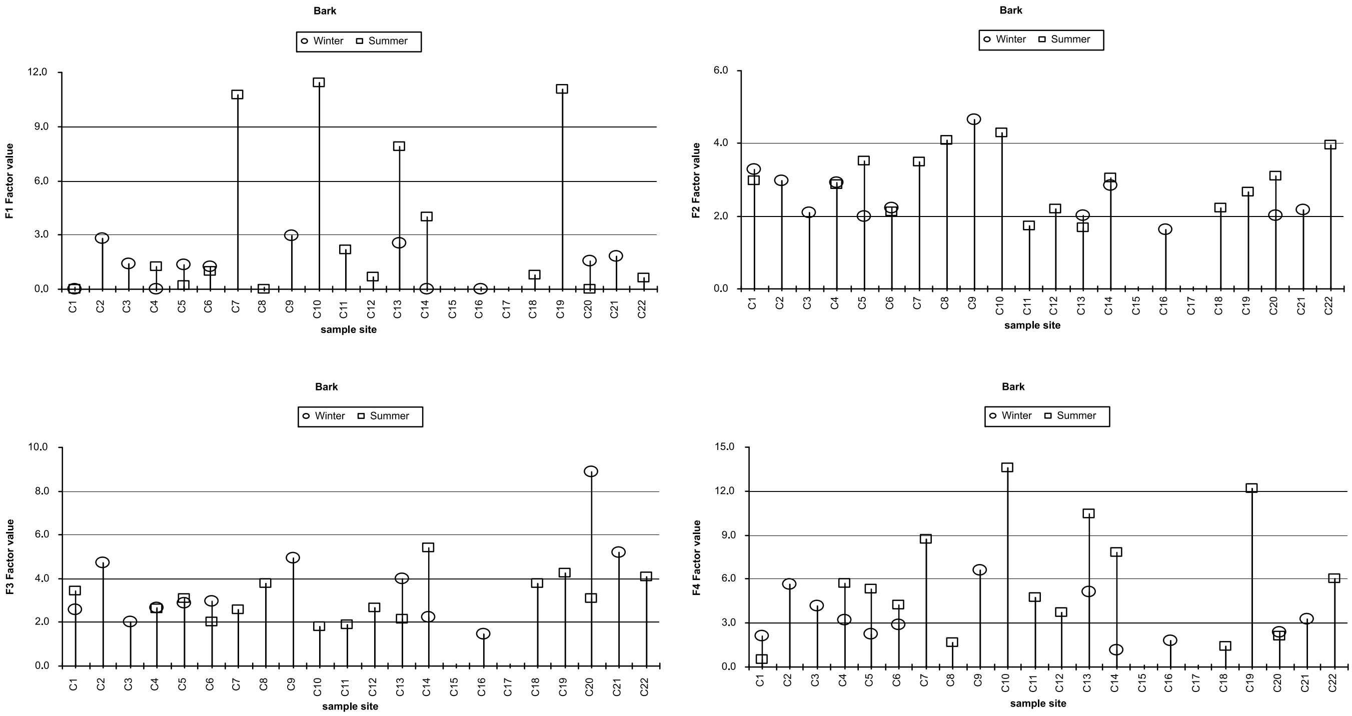

Fig. 3. Contribution of each sampling site to the Factors F1, F2, F3, F4 obtained by MCTTFA, using bark as biomonitor exposed in summer and winter periods. C1, ..., C22 refer the bark samples exposed in Lisbon school sites 1, ..., 22.

out, rather than combustion processes) [24]. The association between Zn and Sb with vehicles and the importance of this source in the centre of Lisbon has been demonstrated before [15, 16]. A Se source, containing also Co, Fe, Hf, La, Sb, Sc, was identified in Factor 3. In the north of Lisbon, Se contents 1000 higher in PM_{10} and $PM_{2.2}$ were registered in 2001, compared with selenium concentrations measured in other urban and industrialized areas of Portugal (0.5–1 ng m^{-3}) [26]. Factor 4 represents the sea contribution, with high factor loading for Na (pilot element), and also Co, Fe, Hf, La, Sc, Se.

Fig. 3 shows the factor values calculated for bark for both winter and summer campaigns, by school site (C1...C22). No significant differences (using a paired Student's *t*-test, 95%) were found between campaigns. Fig. 4 shows the factor values calculated for lichen for both winter and summer campaigns, by school site (L1...L22). A significant difference (using a paired Student's *t*-test) was found for Factor 3 only with higher factor values in summer. When the circles which represent winter campaign values or the squares which represent summer campaign values are not shown, that means lost sample.

Higher element contributions for Factor 1 (Fig. 3) were by traffic from schools 7, 10, 13, 14, and 19. Schools 7, 10, 13, and 14 are near the busy road *Eixo Norte-Sul*, which crosses Lisbon from north to south to distribute more efficiently the traffic through the city; school 19 is near *Avenida da Liberdade*, the main *via* to downtown area. It was expected similarity between contributions of schools 18 and 19, because of their closeness but this was not observed, maybe due to specific school characteristics of the courtyards where bark was exposed. School 18 is inside a building, surrounded by compact buildings area (it is the only one with these characteristics among the studied ones). Factor 2 is similar for all studied area in winter and summer. Lisbon is then a large urban area with an anthropogenic source influencing the whole area. This may indicate traffic as the main source in Factor 2. School 20 is a site with Se source identified in Factor 3. It is situated (see Fig. 1) near an industrial area in the north of Lisbon. In this case, there is a local source with higher contribution in winter when the industrial sources are more active, thus emitting higher levels of Se. The schools with higher contribution to Factor 4 are the same as in Factor 1, also with higher contribution in summer than in winter. These schools are positioned from north to south (see Fig. 1) and Na is carried in sea-spray brought by the northern winds (predominant direction in summer). With the lichen dataset (Table 2), the number of factors given by MCTTFA was 5, one more than for bark due to conductivity. Except for the physiological source, the factors given by lichen dataset do not differ from the ones by bark. Soil source was identified in Factor 1 which is associated to Fe – pilot element, Co, Cr, Hf, La, Na, Sc, Se; traffic was identified in Factor 2 which is associated with Cr – pilot element, Fe, Hf, Sb, Sc, Zn. Conductivity, a physiological source, was identified in Factor 3. A Se source was identified in Factor 4, with Se as a pilot element, and Co, Fe, La. Factor 5 represents the sea contribution, with Na as pilot element, and Fe, Hf, Sc. A significant difference (using a paired Student's *t*-test, 95%) was found for factor 3 with higher factor values in summer. This result shows that lichens in summer presented less vitality (higher conductivity) than in winter. This may be due to the higher temperature and lower humidity [3], and probably not to air pollution. The most significant element contribution to Factor 1 (Fig. 4) was Fe. Table 1 shows that Fe increased from summer to winter for both lichen and bark. Lichen and barks can absorb Fe in the same conditions [29]. In soils with different Fe concentrations, lichen has the same Fe enrichment, whereas bark can take different Fe concentra-

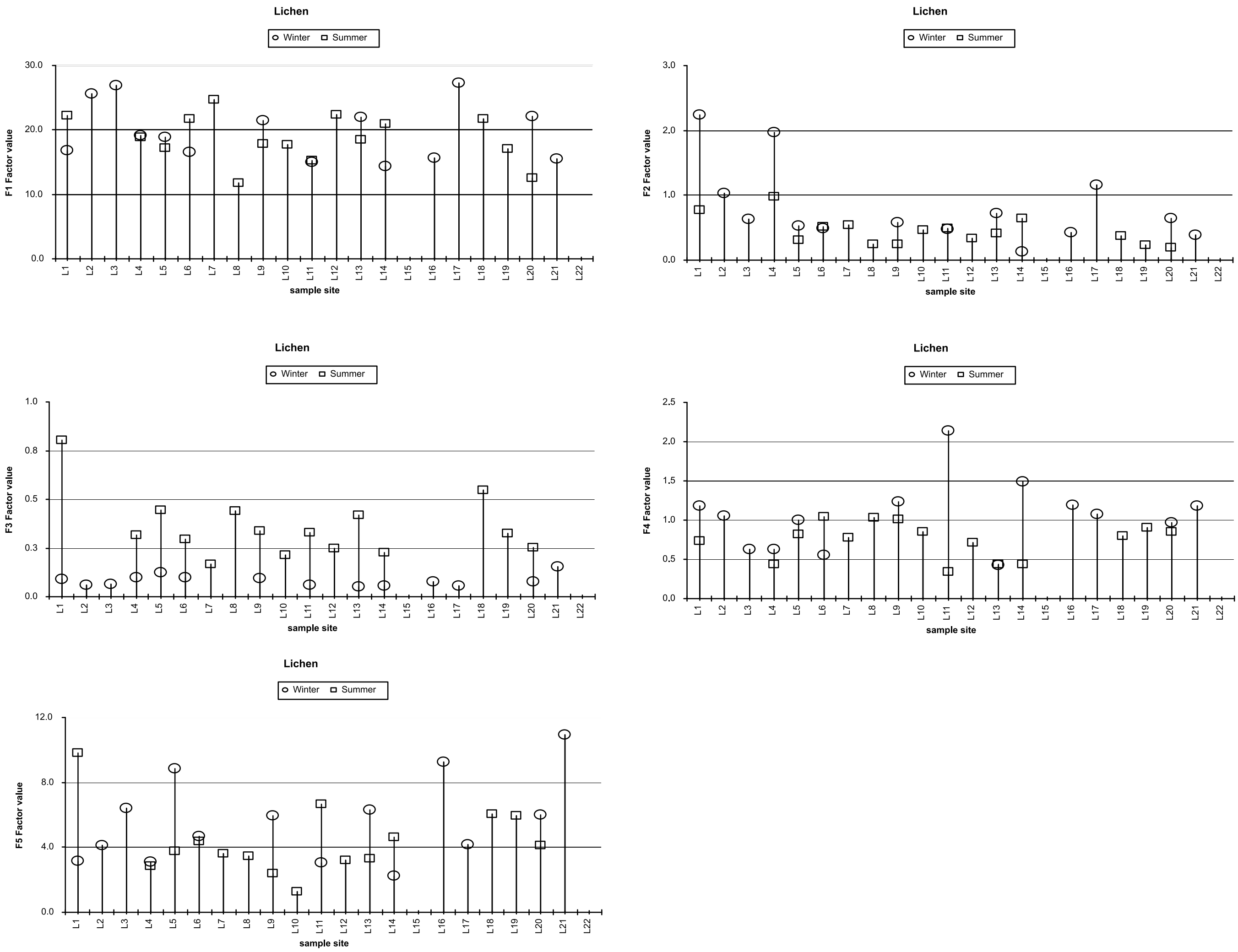

Fig. 4. Contribution of each sampling site to the Factors F1, F2, F3, F4, F5 obtained by MCTTFA, using lichen as biomonitor exposed in summer and winter periods. L1, ..., L22 refer the lichen samples exposed at Lisbon school sites 1, ..., 22.

tions [30]. This explains why different bark locations present different Fe absorption and the same locations present the same Fe uptake by lichens. Pacheco *et al.* [33] verified that lichen and bark absorbed Fe in the same conditions, and that there was a good correlation between Fe absorption by bark or by lichen. Godinho *et al.* [25] observed elemental enrichments of factors during lichen exposure to contaminated areas and their loss during sequent exposure to clean areas. This explains Fe concentrations growth from the unexposed samples to exposed samples. The spatial distribution of schools shows that Factor 2 is traffic contaminated soil resuspension School 1 (see Fig. 1) is near *2ª Circular* (the main internal Lisbon surrounding via) and also near an *industrial area in the North of Lisbon*. School 4 (see Fig. 1) is near *Avenida Infante D. Henrique* (main road along the Tagus river) and the *industrial area of the North of Lisbon*. School 3 might have presented a differentiation too because it was located close to schools 1 and 4; however, this differentiation was not observed probably because school 3 is located away from the higher traffic roads and avenues, surrounded by buildings. Seasonal differentiation was observed with higher values in winter. The activity of factories and intensity of traffic on those roads is higher in winter leading to seasonal differentiation. Freitas *et al.* [34] verified that all the soil resuspension elements have higher levels in the atmosphere during the winter. The conductivity of exposed lichens was higher in schools 1 and 18 in summer. School 1 is near the international airport of Lisbon, therefore lichen conductivity is higher during summer probably due to the increased air traffic during this season. School 18 is located not far from downtown, surrounded by buildings, making it a confined space where chemical element concentrations and climatic conditions cannot vary much. Se (Factor 4) concentrations are higher in winter (see Table 2), increases from the unexposed to the exposed lichens and decreases from winter to summer (see Table 1). School 11 shows the highest contribution to Factor 4; it is close to Tagus river and the influence may be from southwestern winds which bring Se from the Atlantic Ocean. All the other schools present equivalent contributions which are most probably caused by the Se source at the northern industrial area [26].

4. Conclusions

In this work we conclude that lichen conductivity can be a measure of different meteorological conditions but it was not demonstrated that it might be a measure of air pollution. Conductivity was found to be correlated with Tb and Yb in winter, very few elements to proof the good performance of conductivity vs the elemental concentrations. Bark and lichen, when mean values were considered, had mostly different responses even sometimes reversed; however both gave the same information on emission sources in Lisbon. The visualized sources relate soil, traffic, Se source and sea spray; however they are not pure, they show contamination of the natural sources by the anthropogenic and the other way around. Considering the kind of study done, it can be said that one aerosol sampler in Lisbon might be enough to define the emission sources.

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