Revista
Geama

www.geama.ufrpe.br

Bioindicators of Air Quality Species

Cleuma Christir da Silva Almeida[1*], Thyêgo Nunes Alves Barreto [2], Elizabete Buonora de Souza Lira [3], Emmanuelle Maria Gonçalves Lorena [4], Itala Gabriela Sobral Santos [5] and Ana Paula Xavier Gondra Bezerra [6]

Artigo recebido em 11/11/2016 e aceito em 17/05/2017

ABSTRACT

The objective of this research was to identify the bioindicators (trees and lichens) studied and published in scientific articles worldwide between 2013 and 2016, related to atmospheric pollution, besides pointing out the factors that influence the concentration of these pollutants. A literature review was carried out based on scientific articles published between 2013 and 2016. The most studied lichen species were *Flavoparmelia caperata* (L.), *Evernia prunastri* (L.) Ach., *Parmelia sulcata* Taylor, *Pseudevernia furfuracea* L. Zopf, all cited in at least 2 studies. In contrast, forest species were poorly studied, making it impossible to indicate the species that are considered as bioindicators, requiring further studies. The concentrations of PAHs and heavy metals in the atmosphere influenced the diversity and distribution of both lichens and tree species, and may be related to the sensitivity of some species to the others. Such concentrations are influenced by climate changes, humidity, direction of the winds, altitude, different uses and occupation of the soil, distance and type of pollution. The bioindicators raised were quite relevant, however, lacking a methodological standardization, making more intraspecific and interspecific comparisons difficult.

Keywords: atmospheric pollution, tree, lichens.

Espécies Bioindicadoras da Qualidade do Ar

RESUMO

A pesquisa teve como objetivo identificar os bioindicadores (árvores e líquens) estudados e publicados em artigos científicos a nível mundial entre 2013 e 2016, relacionados a poluição atmosférica, além de apontar os fatores que influenciam na concentração desses poluentes. Foi realizado um levantamento bibliográficos com base em artigo científicos publicados entre os anos de 2013 a 2016. As espécies de líquens mais estudadas foram *Flavoparmelia caperata* (L.), *Evernia prunastri* (L.) Ach., *Parmelia sulcata* Taylor, *Pseudevernia furfuracea* L. Zopf, todas citadas em pelo menos 2 estudos. Em contra partida, as espécies florestais foram pouco estudadas impossibilitando a indicação das espécies que são consideradas bioindicadoras, necessitando de maiores estudos. As concentrações de PAHs e metais pesados na atmosfera influenciaram na diversidade e distribuição das espécies tanto dos líquens, quanto nas espécies arbóreas, podendo estar relacionado a sensibilidade que umas podem apresentar em relação as outras. Tais concentrações são influenciados pelas mudanças climáticas, umidade, direção dos ventos, altitude, diferentes usos e ocupação do solo, distância e tipo de poluição. Os bioindicadores levantados mostraram-se bastantes relevantes, no entanto falta uma padronizações metodológicas, dificultando maiores comparações intraespecífico e interespecífico.

Palavras-chave: poluentes atmosféricos, líquens, árvore.

[1]Mestre em Engenharia Ambiental, Universidade Federal Rural de Pernambuco - Recife, Pernambuco, Brasil.
*cleumaufrpe@gmail.com
[2]Doutor em Ciência Florestal, Universidade Federal Rural de Pernambuco - Recife, Pernambuco, Brasil.
[3,4,5,6] Mestranda em Engenharia Ambiental, Universidade Federal Rural de Pernambuco - Recife, Pernambuco, Brasil.

Introduction

Over time the world population has been changing the broadly environment with the launch of numerous chemicals on aquatic ecosystems, terrestrial and atmosphere, as well as increased consumption of products from natural environments through mineral extraction, exploration oil, suppression of natural resources, among others, responsible for the release of polluting elements in air, soil and water.

The urbanization process creates a series of environmental problems, such as the lack of basic sanitation, generating residential sewage streams in water courses, as well as the irregular disposition of solid waste (SILVA et al., 2015; LIRA et al., 2017; SANTANA and COELHO-JUNIOR, 2017).

Air pollution is also a major problem in large urban centers (COSTA and MINEO, 2013), as the world population is increasing the consumption of products from natural environments by mining, oil exploration, natural resources suppression, among others, responsible By the release of non-air, soil and pollutant elements from the water.

The verb polluting is of Latin origin, *polluere* and means defiling, stain, dirty (SÁNCHEZ, 2013).

The term air pollution is very wide may be indicative of the presence of solid, liquid or gaseous suspension, above those considered acceptable by environmental organizations levels, these may be issued directly by emission sources or formed in the atmosphere through chemical reactions.

The CONAMA Resolution n.3 of 28 June 1990 considers as air pollutants any form of matter or energy with intensity, quantity and concentration at odds with the established levels, and what become or can make improper air to humans, the fauna and flora.

The pollutants Divided may be into primary and secondary, primary Are those released directly from emission sources, like the sulfur dioxide (SO2), hydrogen sulfide (H2S), Nitrogen oxides (NOx), an ammonia (NH3), carbon monoxide (CO), carbon dioxide (CO2) and methane (CH4). The secondaries are those formed in the atmosphere through the Chemical areações between primary pollutants, such as hydrogen peroxide (H2O2), sulfuric acid (H2SO4), nitric acid (HNO3), trioxide Sulphur (SO3), Nitrates OS (NO3), OS sulfates (SO42), ozone (O3) and nitrate peroxyacetyl - PAN - (CH3 = OO2NO2), being the last two are among the most harmful the People and vegetation (FREEDMAN 1995 apud PEDROSA , 2007).

There is still hydrocarbons, volatile organic compound (VOC), mercury (Hg), and particulate matter (PM), corresponding to particles suspended with smaller diameter than 50μm, which may contain toxic elements such as arsenic (As), lead (Pb), copper (Cu) and the level (Ni) (FREEDMAN, 1995 apud PEDROSA, 2007).

Biomonitoring can indicate the environmental conditions with the use of species with higher sensitivity to pollutants, disappearing or multiplying, that is, the size and composition of plant and animal communities change (NEUMANN-LEITÃO; EL-DEIR, 2009).

The Environmental quality indicator enables qualitatively and quantitatively monitor air pollution levels, soil and water cheaply, quickly and efficiently through organisms of the environment status indicators. They have a reaction with low doses in short time scale (NEUMANN-LEITÃO; DEIR EL-2009).

But not all living beings are efficient in biomonitoring tests often are absent in polluted areas and not always reveal quantitative answers in order to establish benchmarks, besides the methods do not provide accurate data to the concentrations of pollutants atmospheric due to lack of a methodological standard (KAPUSTA & FREITAS, 2010; LODENIUS 2013).

Among the living beings most searched as biomonitoring alternative of air pollution with tree species, mosses and lichens pointed in some studies as great biomonitors of air quality (MOTA FILHO et al 2007;.. ZARAZÚA-ORTEGA et al, 2013; et SANTOS al. 2014).

Plant species are easier to monitor than animals, for staying in the same place, and the number of individuals who show the same species (NEUMANN-LEITÃO; DEIR EL-2009).

Vascular plants, ie non mosses and lichens, characterized as biomarkers respond to various changes in the environment represented in the organs and tissues of plants, compromising vital functions the same with the accumulation of toxins (CARNEIRO, 2004).

In view of the above, the present research had as objective to identify the bioindicators (trees and lichens) studied and published in scientific articles worldwide between 2013 and 2016, related to atmospheric pollution, besides pointing out the main pollutants as well as the factors that influence the Concentrations.

Material and Methods

The methodology consisted of a bibliographical research based on scientific articles published between the years 2013-2016 referring to bioindicators of atmospheric pollutants.

Results and Discussion

The works of Costa and Mineo (2013) in the passive air quality monitoring in the city of Uberaba, Minas Gerais, Brazil, identified 14 families and 23 genera of lichens. Already Lucheta & Martins (2014) raised in the Botanic Garden of Porto Alegre, RS, 59 species of lichens in 8 families and 17 genera.

The lichens species studied not Period 2013-2016 were *Flavoparmelia caperata* (L.), *Evernia prunastri* (L.) Ach. E *Parmelia sulcata* Taylor, *Parmotrema reticulatum*, *Physcia Laris* (L.) Nyl, *Pyxine cocoes*, *Pseudevernia furfuracea* L. Zopf, *P. hispidula* e *P. sorediata*, Flavoparmelia Caperata, Ramalina celastri, gênero Parmotrema e o Usnea (DANESH et al., 2013; CANHA et al., 2013; STAMENKOVIĆ et al.; 2013; KULARATNE & FREITAS, 2013; ZHURAVLEVA et al., 2013; DANESH et al., 2013; NASCIMBENE et al., 2014; BAJPAI et al., 2014; SANTOS et al., 2014; LOPPI, 2014; KARAKOTI et al., 2014; KAR et al., 2014; MALASPINA et al., 2014; SOARES et al., 2014; VARDARA et al., 2014; MATEOS E GONZÁLEZ, 2016).

One study found three species of epilithic-crustose lichens (*Candelariella* sp., *Lecanora* sp. e *Caloplaca* sp.) as most found in the city of Valencia, Spain for having increased resistance to the effects of pollution on the same (BOSCH-ROIG et al., 2013).

The difference in pollutant concentrations within species lichen may be related to the morphology of each species, *Pyxine cocoes* presented fluorescence rate and chlorophyll affected by Pb (lead), Cu (copper), Fe (iron) and Cr (chromium) (KARAKOTI et al ., 2014), while *Flavoparmelia caperata* shown with greater affinity with the al pollutants (aluminum), Cr, Fe, Pb and Zn (zinc) and pollutants polycyclic aromatic hydrocarbons (PAHs), as the P. hispidula have with Fe and Pb (Bajpai et al., 2014).

A study in the city of Nis in Serbia indicated that the majority of the polluting elements were higher in *Parmelia sulcata* Taylor with a tendency to accumulate Fe, Mn (manganese), Ni (nickel), and Ti (thallium), while *Evernia prunastri* (L.) Ach. , Cu (STAMENKOVIC et al., 2013). By contrast, lichens species *Flavoparmelia caperata* (L.) showed high levels of Al, Ca (calcium), Fe, K (potassium), Mg (magnesium) in a study conducted in Portugal (CANHA et al ., 2013).

Analyzing the verification of PAHs uptake in species of lichens in the sampled stations during the different periods of exposure, Käffer et al. (2013), showed the presence of PAHs in species of lichen, detecting in all stations sampled, both in the control samples and different exposure periods.

Areas with higher occurrence of activities with potential polluter showed less diversity and distribution of species of lichens and see versa (COSTA & MINEO, 2013; ATTANAYAKA & WIJEYARATNE, 2013) similar to those found in San José in Costa Rica, where there was a high level pollution in densely populated neighborhoods, which reflected in the low coverage of lichens in urban parks studied along the wind passage (BUSTAMANTE et al., 2013) confirm the results of Stamenković et al. (2013), where the pollutants metals were influenced by the direction of the wind that carries particulate emissions from agriculture, traffic, landfills and industries close to the city and to other locations. In areas with high altitude (1.400 and 1.800 m above sea level) Italy indicated that the Pb content found in lichen species *Pseudevernia furfuracea* (L.) Zopf have not studied the site, but may be linked to densely populated areas Switzerland and France (LOPPI, 2014).

High humidity is another important factor in increasing the capacity of lichens to incorporate the chemical elements (CANHA et al., 2013).

The seasons can also influence the variation of pollutant in the air, with higher concentrations during the summer and lower in winter due to the amount and frequency of rainfall that facilitates the dispersion thereof (KULARATNE & FREITAS, 2013), but these results differed from work Kar et al. (2014), where metals such as Zn, Pb and Cu were higher than in winter due to greater abundance of atmospheric particles derived primarily from vehicle and industrial emissions; and Malaspina et al. (2014), which pointed out the winter as a factor favoring the highest concentrations of pollutants, even the chemical elements having shown similar results both in summer and winter, except for the Al and Ca and Na (sodium) and Ti where last two are shown three times in summer, moreover, the winter period can be the most favorable for the lichen metabolism.

A study conducted in Santa Maria, Rio Grande do Sul in Brazil near a rectifier batteries showed that the absorption of anthropogenic lead by populations of lichens was 43-141 times higher than the statements of the witnesses, showing that there is pollution source air and wind current, precipitation and humidity influence in reducing the concentration of Pb (SOARES et al., 2014).

The distance is also indicated as a limiting factor in the concentration of pollutants polycyclic aromatic hydrocarbons (PAHs), because the shorter distances of the roads with vehicular emissions have higher levels of these pollutants in epiphytic lichen species *Pseudevernia furfuracea* (NASCIMBENE et al., 2014) . Studies reveal that the use and occupation of land also favor higher pollutant concentrations in lichens, which in turn influence their morphology. Fluorescence rate and chlorophyll are affected by Pb, Cu , Fe and Cr in kind *Pyxine cocoes* when located in industrial areas (sugar mill), followed by increased traffic (KARAKOTI et al., 2014), corroborating Kularatne & Freitas (2013) found that the highest total accumulation of heavy metals (Cr , Cu , Pb and Zn) also in industrial areas , followed by commercial and residential , respectively.

The pollutant concentrations in *P. caperata* is influenced by increased vehicle traffic (KAR et al., 2014). The concentrations of PAHs , heavy metals found in *Remototrachyna awasthii* were higher in areas with vehicular activities derived diesel and gasoline engine (BAJPAI et al., 2013) and may have chemical concentrations that exceeded 200 % for Ca and 42 % of S (sulfur) in areas near urban areas (SANTOS et al., 2014). Similarly, SO2 and NO2 concentrations were quite high in areas with traffic, being strongly associated with the land use (MATEOS & GONZÁLEZ, 2016).

A study in the Arctic was performed in terrestrial habitats and glaciers both the ice-free areas, as in ice-covered region with use of lichens and cryoconite, showing that the heavy metals, is highest in areas of low elevation, and al and Fe were found in cryoconite samples, while al was also present in high quantities in seven of the eight studied lichens samples (SINGH et al., 2013).

Few studies carried out in the period 2013-2016 were related to arboreal bioindicators for the evaluation of air quality.

Maki et al. (2013) presented a literature review of studies that referred to the bio-indicators in air pollution biomonitoring, regardless of the publish period, so were related 19 species in 27 studies, 16 belonging to the Division Angiospermae, 1 genre the Bryophyta, and 2 lichens.

Petkovsek (2013) monitored during 1991 and 2008, the forest ecosystem, which is the largest Slovenian power plant (Noroega) and realized that the total sulfur concentrations were high similar to other studies, where its altitude coincides with the frequent temperature inversions.

The bioindicators of air quality are scarce (*Myracrodruon urundeuva*, *Croton floribundus*, *Piptadenia gonoacantha*, *Tilia tomentosa* L., *Tilia Cordata* Mill., *Aesculus hippocastanum* L., genus *Gladiolus* sp.), when dealing with arboreal species (TODOROVIC et al., 2013; SANTOS et al., 2014; SUNDAYS et al., 2015; PROSKURA, 2015).

A study in Sobradinho in the Federal District in Brazil, found that there were high levels of the elements Fe, Cu, Zn, Al, S and Ba (barium) found in the bark of the mastic *Myracrodruon urundeuva* originating from the vicinity of the cement plant , extraction limestone for cement production and which passes traffic of heavy vehicles for trans- porting the products are produced (SANTOS et al., 2014).

A phytosociological survey, conducted in Campinas, São Paulo in Brazil, pointed out three forest species as more abundant species inventoried are they *Croton floribundus* and *Piptadenia gonoacantha,* in order to study the same leaves to know the composition of air pollutants, but showed distinct behaviors, where *P. gonoacantha* species showed concentrations of PAHs while *C. floribundus* provided features on the potential effects of oxidative pollutants such as O3 (SUNDAYS et al., 2015).

There are indications that there are no significant differences between the activities of radionuclides in soil and leaves (*Tilia tomentosa* L. e *Tilia cordata* Mill) and *Aesculus hippocastanum* L. as biomonitors of radionuclides in different locations in the central area city, indicating that significant concentrations are in the soil, which may occur at root absorption as the main mechanism of its accumulation in leaves Todorovic et al. (2013).

Lichens are especially beings adapt to extreme environments with temperature and humidity, as well as being sensitive to urban pollution, providing answers not only quantitative but also qualitative . Additionally the fungi lichenized occur in various types of substrate such as tree bark, leaves, rock, soil, mosses, a characteristic that enables its identification because certain species are quite selective (SPIELMANN; MARCELLI; CERATI, 2006). Lichens have no stomata, which means gases may be absorbed by the thallus and quickly spread over the photobiont (KÄFFER, 2013).

Several studies cite Cladonia verticillaris as a kind of lichens which presents variations in its morphology (SILVA, 2002; PEREIRA, 2011) and physiology (FREITAS, 2006; MOTA FILHO et al., 2007) when exposed to environments with pollutants in the air, particularly with heavy metals and other materials dispersed even in small quantities (SILVA, 2002; PEREIRA, 2011).

The predominant wind direction is a blunt pollutant dispersion factor (FREITAS, 2006; MOTA FILHO et al., 2007). The greatest distance (200 meters) of pollution in areas cause greater dispersion of lead in the air and thus cause less impacted in lichens (MOTA FILHO et al., 2007). The species of lichens *Canoparmelia texana*, *Pictish dirinaria* and *Punctelia graminicola* are tolerant of pollution , as showed less sensitivity in the city of Canoas, RS (MARTINS et al ., 2008).

Urbanization gradients associated with higher humidity, altitude and temperature influence the reduction in lichens (MENEGHINI et al. 2012).

The most studied species of lichens were *Flavoparmelia caperata* (L.), *Evernia prunastri* (L.) Ach., *Parmelia sulcata* Taylor, *Pseudevernia furfuracea* L. Zopf, all cited in at least two studies, followed by *Parmotrema reticulatum*, *Physcia laris* (L.) Nyl, *Pyxine cocoes*, *P. hispidula* e *P. sorediata*, *F. Caperata*, *Ramalina celastri*, gênero Parmotrema e o Usnea, with only one citation each.

By contrast, the forest species have been little studied, complicating an indication of the most used species and concentrations of pollutants and the consequences of these species.

The concentrations of PAHs, heavy metals in the atmosphere influence the diversity and distribution of both species of lichens, and in the tree species may be related to a sensitivity that may have more than others.

Such concentrations of these pollutants are influenced by climate change, humidity, wind direction, altitude, different uses and occupation, distance and type of pollution.

The bioindicators raised proved to be quite relevant, however, the species, both arboreal lichens as presented different methodologies difficult largest comparisons. Thus, each environment requires different sampling because the highly disturbed sites homogeneous areas and the number of trees should be higher sampling unit, due to the greater variability of lichen diversity (GIORDANI et al., 2013).

As for the pollutants found in the studies, a Table 1 presents as main anthropic sources of pollution, as well as the risks to human health and the environment.

Table 1. Gaseous pollutants causing environmental risks and human health.

Pollutants	Anthropic source	Environmental risk and / or health
Aluminum (Al)	Industrial, automobile emissions, cigarette smoke, artificial colorings, pesticides residues in food, paper, ceramics, glass, textiles, food processing and drug packaging industries, household appliances, construction.	It may be associated with Alzheimer's disease.
Zinc (Zn)	Activities mining, steel production, batteries, fertilizers, rims and car wheels, paints, plastics, rubber, tire wear, automotive oils, burning of waste and coal.	kidney failure, ulcers, pancreatitis, anemia, bone dystrophy and neurological disorders.
Cálcio (Ca)	Production of metal alloys, load paper and paints, chemical fertilizer, concrete and cement.	Not found.
Potássio (K)	Production glasses, drugs and ammunition.	Not found.
Chumbo (Pb)	Batteries, steel, fertilizers, automobile scraps, oil industry, paints and dyes.	Contamination of surface waters and aquifers. In humans there is an attack on the brain and kidneys, causes anemia.
Lead (Pb)	Batteries, steel, fertilizers, automobile scraps, oil industry, paints and dyes.	Contamination of surface waters and aquifers. In humans there is an attack on the brain and kidneys, causes anemia.
Nickel (Ni)	Manufacture of batteries, petroleum products,	Not found.

	pigments, diesel fuel, lubricating oil, brakes, asphalt pavement, industrial effluents.	
Copper (Cu)	Used in the electrical industry, construction, automotive parts, household appliances, wood preservatives, paints, insecticides, etc.	It reduces the absorption of iron, leading to bone weakening, cardiac lesions, anemia, hypertension, asthma, and other damage.
Iron (Fe)	Issued by mining, industrial activities of iron and steel, welding, metal polishing wear of automotive parts.	Respiratory diseases.

Adaptation: Alves et al. (2008); Poleto e Castilhos (2008); Baldissera (2007); Prochnow, 2005; Ramamoorthy & Moore (1984).

Conclusions

The lichen species were more studied than the trees, were: Flavoparmelia caperata (L.), Evernia prunastri (L.) Ach., Parmelia sulcata Taylor, Pseudovirus, Furfuracea L. Zopf.

Several pollutants were related to human activities in the environment, influenced by climate change, humidity, direction of the winds, altitude, use and occupation of the land, distance from the polluting source and the type of pollution. The bioindicators raised were quite relevant, however, both lichen and tree species different methodologies, making it difficult to compares them.

References

ALVES, J. C.; SOUZA, A. P.; PÔRTO, M. L.; ARRUDA, J. A.; JÚNIOR, U. A. T.; SILVA, G. B.; ARAÚJO, R. C.; SANTOS, D. A. 2008. Absorção e distribuição de chumbo em plantas de vetiver, jureminha e algaroba. Rev. Bra. Ciência do Solo, v. 32, p.1329-1336. Acesso: 19 out. de 2016.

ATTANAYAKA, A. N. P. M.; WIJEYARATNE, S. C. 2013. Corticolous lichen diversity, a potential indicator for monitoring air pollution in tropics. J. Natn. Sci. Foundation Sri Lanka. v.41, n. 2, p.131-140. Acesso: 19 out. de 2016.

BAJPAI, R.; SHUKLA, V.; UPRETI, D. K. 2013. Impact assessment of anthropogenic activities on air quality, using lichen Remototrachyna awasthii as biomonitor. Int. J. Environ. Sci. Technol. v.10, p.1287–1294. Acesso: 19 out. de 2016.

BAJPAI, R.; SHUKLA, V.; UPRETI, D. K.; SEMWAL, M. 2014. Selection of suitable lichen bioindicator species for monitoring climatic variability in the Himalaya. Environ Sci Pollut Res. 21:11380–11394. Acesso: 19 out. de 2016.

BALDISSERA, B. L. p. 94, 2007. Absorção/adsorção de cádmio, cromo e chumbo por Agaricus blazei. Dissertação de mestrado em Ciências Biológicas (Microbiologia Aplicada), Universidade Estadual Paulista. Rio Claro, São Paulo.

BOSCH-ROIG, P.; BARCA, D.; CRISCI, G. M.; LALLI, C. 2013. Lichens as bioindicators of atmospheric heavy metal deposition in Valencia, Spain. J. Atmos Chem. v.70, p.373–388. Acesso: 19 out. de 2016.

BRASIL. Resolução do CONAMA n°03 de 28 de junho de 1990. Dispõe sobre padrões de qualidade do ar. Publicado no D.O.U.

BUSTAMANTE, E. N.; MONGE-NÁJERA, J.; MÉNDEZ-ESTRADA, V. H. 2013. Use of a Geographic Information System and lichens to map air pollution in a tropical city: San José, Costa Rica. Rev. Biol. Trop., v. 61 n.2, p.557-563. Acesso: 19 out. de 2016.

CANHA, N.; FREITAS, M. C.; PACHECO, A. M. G. 2013. Response of air-pollution biomonitors under three different meteorological conditions. J. Radioanal Nucl Chem. v.295, p.489–496. Acesso: 19 out. de 2016.

CARNEIRO, R. M. A. p. 146, 2004. Bioindicadores vegetais de poluição atmosférica: uma contribuição para a saúde da comunidade. Dissertação de Mestrado (Enfermagem de Saúde Pública) Universidade São Paulo – Escola de Enfermagem em Ribeirão. São Paulo.

COSTA, W. R.; MINEO, M. F. 2013. Os líquens como bioindicadores de poluição atmosférica no município de Uberaba, Minas Gerais, Brasil. REGET, v. 13 n. 13, p. 2690- 2700. Acesso: 19 out. de 2016.

DANESH, N.; PUTTAIAH, E.T.; BASAVARAJAPPA, B. E. 2013. Studies on diversity of lichen, Pyxine cocoes to air pollution in Bhadravathi town, Karnataka, India. Journal of Environmental Biology. vol. 34, 579-584. Acesso: 19 out. de 2016.

DOMINGOS, A.; BULBOVAS, P.; CAMARGO, C. Z. S.; AGUIAR-SILVA, C.; BRANDÃO, S. E.; DAFRÉ-MARTINELLI, M.; DIAS, A.P.L.; ENGELA, M. R. G. S.; GAGLIANO, J.; MOURA, B. B.; ALVES, E. S.; RINALDI, M. C. S.; GOMES, E. P.C.; FURLAN, C. M.; FIGUEIREDO, A. M. G. 2015. Searching for native tree species and respective potential biomarkers for future assessment of pollution effects on the highly diverse Atlantic Forest in SE-Brazil. Environmental Pollution, v. 202, p. 85 – 95. Acesso: 19 out. de 2016.

EZEONYEJIAKU, C. D.; OBIAKOR, M. O. 2013. Spatial Biomonitoring of Trace Element Contamination and Atmospheric Quality Assessment. American Journal of Life Science Researches. v.1, p. 67-73. Acesso: 19 out. de 2016.

FREEDMAN, B. 1995. Environmental ecology. The ecological effects of pollution, disturbance and other stresses. 2 ed. Academic Press Inc, San Diego. Apud PEDROSA, A. N. V. 2007. Poluentes Atmosféricos & Plantas Bioindicadoras. Curso de capacitação de monitores e educadores. Biodiversidade vegetal e meio ambiente. Instituto de Botânica, São Paulo. p. 16.

FREITAS, M. R. p. 58, 2006. Uso de Cladonia verticillaris (Raddi) Fr. (líquen) como biomonitor da qualidade do ar no complexo industrial portuário de Suape – PE. Dissertação (Mestrado em Biologia Vegetal) – Universidade Federal de Pernambuco, Recife.

GIORDANI, P.; BRUNIALTI, G.; FRATI, L.; INCERTI, G.; IANESCH, L.; VALLONE, E.; BACARO, G.; MACCHERINI, S. 2013. Spatial scales of variation in lichens: implications for sampling design in biomonitoring surveys. Environ Monit Assess. v.185, p.1567–1576. Acesso: 19 out. de 2016.

KÄFFER, M. A., LEMOS, A T., APEL, M. A., ROCHA, J. V., MARTINS, S. M. de A., VARGAS, V. M. F. 2012. Use of bioindicators to evaluate air quality and genotoxic compounds in an urban environment in Southern Brazil. Environmental Pollution, v. 163, p. 24-31. Acesso: 19 out. de 2016.

KAPUSTA, S. C.; FREITAS, S. M. F. 2010. Bioindicadores ambientais. IN: Introdução ao gerenciamento ambiental. POLETO, C. Rio de janeiro: Interciência, p.111-179. Acesso: 19 out. de 2016.

KAR, S.; SAMAL, A. C.; MAITY, J. P.; SANTRA, S. C. 2014. Diversity of epiphytic lichens and their role in sequestration of atmospheric metals. Int. J. Environ. Sci. Technol. v.11, p. 899–908. Acesso: 19 out. de 2016.

KARAKOTI, N.; BAJPAI, R.; UPRETI, D. K.; MISHRA, G. K.; SRIVASTAVA, A.; NAYAKA, S. 2014. Effect of metal content on chlorophyll fluorescence and chlorophyll degradation in lichen Pyxine cocoes (Sw.) Nyl.: a case study from Uttar Pradesh, India. Environ Earth Sci. v. 71, p. 2177–2183. Acesso: 19 out. de 2016.

KULARATNE, K. I. A.; FREITAS, C. R. 2013. Epiphytic lichens as biomonitors of airborne heavy metal pollution. Environmental and Experimental Botany, v. 88, p. 24 – 32. Acesso: 19 out. de 2016.

LIRA, E. B. S.; ALMEIDA, C. C. S.; SANTOS, T. C. G.; NORONHA, C. R. B.; MORAIS, A. S. 2017. Soil pollution of urban origin: environmental management of solid waste in the municipalities of Pernambuco center agreste. Rev. Geama. v.8, n.1, p.17-22. Acesso: 19 out. de 2016.

LODENIUS, M. 2013. Use of plants for biomonitoring of airborne mercury in contaminated áreas. Environmental Research v.125, p.113–123. Acesso: 19 out. de 2016.

LOPPI, S. 2014. Lichens as sentinels for air pollution at remote alpine areas (Italy). Environmental Sci Pollut Res. v. 21, p. 2563–2571. Acesso: 19 out. de 2016.

LUCHETA, F.; MARTINS, S. M. A. 2014. Liquens foliosos e fruticosos corticícolas do Jardim Botânico de Porto Alegre, RS, Brasil. Iheringia, Porto Alegre, v. 69, n. 1, p. 29-35. Acesso: 19 out. de 2016.

MAKI, E.S.; SHITSUKA, R.; BARROQUEIRO, C. H.; SHITSUKA, D. M. 2013. Utilização de Bioindicadores em monitoramento de poluição. Biota Amazônica, Macapá, v.3, n.2, p 169-178. Acesso: 19 out. de 2016.

MALASPINA, P.; TIXI, S.; BRUNIALTI, G.; FRATI, L.; PAOLI, L.; GIORDANI, P.; MODENESI, P.; LOPPI, S. 2014. Biomonitoring urban air pollution using transplanted lichens: element concentrations across seasons. Environ Sci Pollut Res. v. 21, p. 12836–12842. Acesso: 19 out. de 2016.

MARTINS, S. M. A.; KÄFFER, M. I.; LEMOS, A. 2008. Liquens como bioindicadores da qualidade do ar numa área de termoelétrica, Rio Grande do Sul, Brasil. Hoehnea, v.35, n.3, p. 425-433. Acesso: 19 out. de 2016.

MATEOS, A. C.; GONZÁLEZ, C. M. 2016. Physiological response and sulfur accumulation in the biomonitor Ramalina celastri in relation to the concentrations of SO2 and NO2 in urban environments. Microchemical Journal, v.125, p.116–123. Acesso: 19 out. de 2016.

MAZZITELLI, S. M. A. M. et al. Utilização de liquens no biomonitoramento da qualidade do ar. In: XAVIER-FILHO, L. et al. Biologia de liquens. Rio de Janeiro: Âmbito Cultural. p. 101-143, 2006. Acesso: 19 out. de 2016.

MENEGHINI, R. L.; PÉRICO, E.; MUSSKPOF, E. L. 2012. Cobertura de liquens em árvores nativas seguindo um gradiente de urbanização na cidade de Estrela, RS. Rev. de Ciências Ambientais, Canoas, v.6, n.2, p. 61- 72. Acesso: 19 out. de 2016.

MOORE, J.W., RAMAMOORTHY, S. 1984. Heavy metals in natural waters. New York: Springer-Verlag, p.328. Acesso: 19 out. de 2016.

MOTA FILHO, F. O.; PEREIRA, E. C.; LIMA, E. S.; SILVA, N. H.; FIGUEIREDO, R. C. B. 2007. Influência de poluentes atmosféricos em Belo Jardim (PE) utilizando Cladonia verticillaris (Raddi) Fr. como biomonitor. Química Nova, v. 30, n. 5, p. 1072-1076. Acesso: 19 out. de 2016.

NASCIMBENE, J.; TRETIACH, M.; CORANA, F.; LO SCHIAVO, F.; KODNIK, D.; DAINESE, M.; MANNUCCI, B. 2014. Patterns of traffic polycyclic aromatic hydrocarbon pollution in mountain areas can be revealed by lichen biomonitoring: A case study in the Dolomites (Eastern Italian Alps). Science of the Total Environment, v. 475, p. 90–96. Acesso: 19 out. de 2016.

NEUMANN-LEITÃO, S.; EL-DEIR, S. 2009. Bioindicadores da Qualidade Ambiental. Instituto Brasileiro Pró-Cidadania, Recife. p.298. Acesso: 19 out. de 2016.

PEREIRA, I. M. C. p. 42, 2011. Biomonitoramento ativo em áreas de Pernambuco: uma perspectiva da influência da cana e de outras fontes poluidoras. Monografia (Geografia) – Universidade Federal de Pernambuco, Recife.

PETKOVŠEK, S. A. S. 2013. Forest biomonitoring of the largest Slovene thermal power plant with respect to reduction of air pollution. Environ Monit Assess, v.185, p.1809–1823. Acesso: 19 out. de 2016.

POLETO, C.; CASTILHO, Z.C. 2008. Impacto por poluição difusa de sedimentos em bacias urbanas. Ambiente e Sedimentos. Porto Alegre: Ed. ABRH, p. 193-227.

PROCHNOW, T. R. p.274, 2005. Biomonitoramento de metais em suspensão atmosférica na sub-bacia do Arroio Sapucaia, RS-Brasil. Tese de Doutorado em Ecologia, Universidade Federal do Rio Grande do Sul.

PROSKURA, N. 2015. Bioindication And Biomonitoring Of Air Pollution. Life Science Journal, v.12, n.8, p.3. Acesso: 19 out. de 2016.

SANTANA, J. F. C.; COELHO-JÚNIOR, J. M. 2017. Sanitary exhaustion in Abreu e Lima city: The shocks caused in Timbó river. Rev. Geama, v.8, n.1, p.29-36. Acesso: 19 out. de 2016.

SANTOS, C. M.; OLIVEIRA, R. C.; ROIG, H. L.; RÉQUIA JÚNIOR, W. J. 2014. Biomonitoramento passivo com casca de aroeira vermelha (Myracrodruon urundeuva Lorenzi Harri) para verificar a variabilidade espacial da poluição atmosférica em uma região do Distrito Federal, Brasil. Artigo técnico. Eng Sanit Ambient, v.19 n.4, p453-460. Acesso: 19 out. de 2016.

SANTOS, E. P.; FIOREZE, M.; KEMERICH, P. D. C.; BENTO, A. P.; O. CARVALHO JÚNIOR. 2014. Uso de liquens e da técnica de espectrometria de fluorescência de raios-x por energia dispersiva para monitoramento da qualidade do ar. Rev. Geociências, v. 33, n. 1, p.61-72. Acesso: 19 out. de 2016.

SILVA, J. F.; FERREIRA, H. S.; SANTOS, M. O. 2015. Considerações sobre os estudos em clima urbano. Revista GEAMA, Recife, v.2, n.1, p.156-170.

SILVA, R. A. p. 148, 2002. Cladonia verticillaris (líquen) como biomonitor padrão da qualidade do ar no Distrito de Jaboatão – PE. Dissertação (Mestrado em Gestão e Políticas Ambientais) – Universidade Federal de Pernambuco, Recife. Acesso: 19 out. de 2016.

SINGH, S. M.; SHARMA, J.; GAWAS-SAKHALKAR, P.; UPADHYAY, A. K.; NAIK, S.; PEDNEKER, S. M.; RAVINDRA, R. 2013. Atmospheric deposition studies of heavy metals in Arctic by comparative analysis of lichens and cryoconite. Environ Monit Assess. v.185, p.1367–1376. Acesso: 19 out. de 2016.

SOARES, J. F.; ILHA, R.; ZAZYCKI, M. A.; BERNARDES, R. C. C.; MORTARI, S. R.; VASCONCELLOS, N. J. S.2014. Absorção de chumbo antrópico por populações de liquens do gênero Usnea em área industrial. Rev. Monografias Ambientais - REMOA, v.13, n.5, p.3831-3836. Acesso: 19 out. de 2016.

SPIELMANN, A. A.; MARCELLI, M. P.; CERATI, T. M. Fungos Liquenizados (Líquens). 2006. Disponível em: < http://www.biodiversidade.pgibt.ibot.sp.gov.br/Web/pdf/Fungos_Liquenizados_Spielmann_&_Marcelli.pdf > Acessado em: 2 maio de 2016.

STAMENKOVIĆ, S. S.; MITROVIĆ, T. L. J.; CVETKOVIĆ, V. J.; KRSTIĆ, N. S.; BAOŠIĆ, R. M.; MARKOVIĆ, M. S.; NIKOLIĆ, N. D.; MARKOVIĆ, V. L. J.; CVIJAN. M. V. 2013. Biological indication of heavy metal pollution in the areas of donje Vlase and cerje (southeastern serbia) using epiphytic lichens. Arch. Biol. Sci., Belgrade, v.65, n.1, 151-159. Acesso: 19 out. de 2016.

TODOROVIĆ, D.; POPOVIĆ, D.; AJTIĆ, J.; NIKOLIĆ, J. 2013. Leaves of higher plants as biomonitors of radionuclides (137Cs, 40K, 210Pb and 7Be) in urban air. Environ Sci Pollut Res. v.20, p.525–532. Acesso: 19 out. de 2016.

VARDARA, C.; BASARANA, E.; CANSARAN-DUMANB, D.; ARASA, S. 2014. Air-quality biomonitoring: Assessment of genotoxicity of air pollution in the Province of Kayseri (Central Anatolia) by use of the lichen Pseudevernia furfuracea (L.) Zopf and amplified fragment-length polymorphism Markers. Mutation Research, v. 759, p. 43– 50. Acesso: 19 out. de 2016.

ZARAZÚA-ORTEGA, G.; POBLANO-BATA, J.; TEJEDA-VEGA, S.; ÁVILA-PÉREZ, P.; ZEPEDA-GÓMEZ, C.; ORTIZ-OLIVEROS, H.; MACEDO-MIRANDA, G. 2013. Assessment of Spatial Variability of Heavy Metals in Metropolitan Zone of Toluca Valley, Mexico, Using the Biomonitoring Technique in Mosses and TXRF Analysis. The Scientific World Journal, p. 1-7. Acesso: 19 out. de 2016.

ZHURAVLEVA, S. E.; BONDARENKO, P. V.; TRUKHAN, E. M. 2013. Biomonitoring of Indicator Species of Lichen by EPR Spectroscopy. Biophysics. v.58, n.2, p. 240–244. Acesso: 19 out. de 2016.