Bioindicators of Air Quality Species
Cleuma Christir da Silva Almeida1*, 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

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.

1 Mestre em Engenharia Ambiental, Universidade Federal Rural de Pernambuco - Recife, Pernambuco, Brasil.
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.

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 influenciaram na concentração desses poluentes. Foi realizado um levantamento bibliográfico com base em artigos 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 contrapartida, 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 influenciadas pelas mudanças climáticas, umidade, direção dos ventos, altitude, diferentes usos e ocupação do solo, distância e tipo de poluição. Os bioindicadores levantados mostraram-se bastante relevantes, no entanto falta uma padronização metodológica, dificultando maiores comparações intraespecífico e interespecífico.

Palavras-chave: poluentes atmosféricos, líquens, árvore.
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-oil exploration oil, suppression of natural resources, environments through mineral extraction, increased consumption of products from natural ecosystems, terrestrial and atmosphere, as well as launching numerous chemicals on aquatic ecosystems, terrestrial and atmosphere, as well as changing the broadly environment 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 biointicators (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.

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 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 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 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 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.
Results and Discussion


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 Malaspinia 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 *Pxyine 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 (*Myrracrodrunon urundeuva, Croton floribundus, Piptadenia gonoanatha, 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 *Myrracrodrunon 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 gonoanantha*, in order to study the same leaves to know the composition of air pollutants, but showed distinct behaviors, where *P. gonoanantha* 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*, género 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 | \begin{tabular}{l} \textbf{Zinc} (Zn) \\ Activities mining, steel production, batteries, fertilizers, rims and car wheels, paints, plastics, rubber, tire wear, automotive oils, burning of waste and coal. \end{tabular} | \begin{tabular}{l} \textbf{Cálculo} (Ca) \\ Production of metal alloys, load paper and paints, chemical fertilizer, concrete and cement. \end{tabular} | \begin{tabular}{l} \textbf{Potássio} (K) \\ Production glasses, drugs and ammunition. \end{tabular} | \begin{tabular}{l} \textbf{Chumbo} (Pb) \\ Batteries, steel, fertilizers, automobile scraps, oil industry, paints and dyes. \end{tabular} | \begin{tabular}{l} \textbf{Nickel} (Ni) \\ Manufacture of batteries, petroleum products, \end{tabular} | \begin{tabular}{l} \textbf{Aluminum} (Al) \\ Industrial, automobile emissions, cigarette smoke, artificial colorings, pesticides residues in food, paper, ceramics, glass, textiles, food processing and drug packaging \end{tabular} | It may be associated with Alzheimer's disease. | Not found. | Not found. | Contamination of surface waters and aquifers. In humans there is an attack on the brain and kidneys, causes anemia. | 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.


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


BRASIL. Resolução do CONAMA nº03 de 28 de junho de 1990. Dispõe sobre padrões de qualidade do ar. Publicado no D.O.U.


