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# Monitoring Air Pollution with Living Organisms. Case Study Use of Lichens as Bioindicators in the Miguel Pereira city, Rio de Janeiro, Brazil

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An alternative route to evaluate air pollution and its impact on the environment is using bioindicators, such as lichens, for example. The main purpose of this paper is to demonstrate that the use of lichens can be a simple and economically feasible way to detect and monitor air pollution. Qualitative and quantitative analyses, such as the survey of the specific richness, coverage and frequency of the lichen flora have been made. They have been calculated based in the Index of Atmospheric Purity (IAP) values obtained through seasonal campaigns carried out from January to October in 2017 at four locations in the Miguel Pereira District – State of Rio de Janeiro. 21 “taxon of lichens” distributed in 09 families and 13 genera have been detected. Locations 3 and 4 (Javary lake and São Roque street) have shown higher values of specific richness and IAP (21.66 and 31.45, respectively) which indicate the air pollution at these locations as being respectively regular and low. On the other hand, at the other two locations (Aurea street and Bus Terminal), the specific richness and IAP values found – 7.91 and 11.23 indicate high and high air pollution, respectively. These values and associated indicators lead to believe that the more urbanized an area is, the higher is its air pollution.

## 1. Introduction

In Brazil, the installation of large-scale industries and the excess of pollutants launched by them, led to acute episodes of pollution between the decades of 60 and 70 in São Paulo State, causing damage to the population's health. In order to control atmospheric pollution, later, in 1972, 14 air quality monitoring stations were installed to measure the concentration of pollutants of Sulphur Dioxide ($SO_2$) and black smoke in the state (CETESB, 2001).

In addition to damage to health and the quality of human life, air pollution can also harm vegetation, the economy and the properties of the atmosphere, producing acidification and potentiating global warming (WANG et al., 2019). Therefore, monitoring is an instrument of paramount importance, not only to control damages, but also to prevent them. However, air quality monitoring occurs in less than 2 % of the Brazilian municipalities. Difficulties such as lack of controlling, shortage of skilled labor and lack of financial resources for the acquisition of equipment and maintenance of networks, can hinder the implementation and maintenance of a monitoring system (IEMA, 2014). So, the question is: how to indicate the atmospheric pollution in cities that do not have air quality monitoring stations and advanced technological resources?

A simple and inexpensive alternative, to evaluate the atmospheric pollution and the impacts caused to the environment, is using living organisms capable of responding measurably to any disturbance in the environment in which they are introduced, and which are called bioindicators (Filho et al., 2006).

The techniques that use bioindicators as monitoring mechanisms, are called bioindications and biomonitoring and unlike mechanical monitoring, which is generally of high cost and offers results of the current and/or momentary situation of the environment studied, monitoring with biological indicators besides having low cost, offers the history of local pollution, as well as the peaks of pollutant concentration, and can be used as a

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complement or at the intersection of information arising from Instrumental automatic stations. Among the most used plant forms for this purpose are the lichen, mosses and, to a lesser extent, some vascular.

Lichens are very sensitive to atmospheric pollution and are among the organisms most used in air biomonitoring studies, since they provide a measurable response to the disturbance or stress of pollutants, especially $SO_2$ e $NO_X$ (VAIRO et al., 2014), presenting morphophysiological changes and structural in the stalk, respond proportionally to the degree of contamination or degradation, have easy taxonomic identification, allow low cost research and have vast geographic distribution of the species (Filho et al., 2006).

Several methodologies were developed with the use of lichens as bioindicators, among which were used in this experiment: Kovács (1992), Poggiani et al. (1996) and Asta et al. (2002); that are based on the survey of the specific richness, absolute frequency and percentage of species coverage from the overlap of a sampling grid in tree trunks. Another method used was the Index of Atmospheric Purity (IAP) of the studied region, developed by De Sloover and Leblanc (1968) and adapted by Rubiano (2002), which allows a quantitative assessment of the level of pollution of a given region.

Thus, this experiment becomes relevant in the sense of contributing to the dissemination of a simple technique of monitoring the quality of air and at the same time economically accessible, assisting the competent organs of the studied city and society as a whole to know the current situation of the air quality of the city, since there is no monitoring system in the city, which is popularly known to occupy the 3rd place in the world ranking of cities with the best microclimate and which also covers in part of its territory two important Brazilian environmental conservation units: the Tinguá Federal Biological Reserve and the Araras State Biological Reserve.

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## 2. Materials and Methods

### 2.1 Place of study

The study was conducted in the municipality of Miguel Pereira, which belongs to the Centro Sul Fluminense region of the state of Rio de Janeiro, Brazil. It is situated at 618 meters of altitude and is located at 22° 27' 14" south latitude and 43° 28' 08" west longitude. It has an estimated population of 24.855 inhabitants over an area of approximately 289.000 $m^2$ (IBGE, 2016). Miguel Pereira integrates the Serra of Consolidated Tourism, mainly of ecological character, and includes in part of its territory two important conservation units: The Federal Biological Reserve of Tinguá and the Biological State of the Araras Reserve.

### 2.2 Sampling points

The region of the case study was mapped in two areas: one central (more urbanized) and another peripheric (less urbanized), being the second more distant from the center of the city. For each zone, two sampling points were selected.

The points in each zone were chosen according to the average flow of motor vehicles per minute, and were checked three times: at 08:00 am, 12:00 pm (rush hours) and 17:00 pm hours. Vehicle sampling was carried out for 7 days: Monday to Friday (days of least movement) and Saturday and Sunday (days of great movement of tourists in the city). In each sampled schedule, the number of vehicles was recorded in 1 minute (60 seconds) and after the average of these values was calculated. Finally, the average of the 7 days was calculated.

*Table 1: Classification of sampling points.*

| Zone | Point | Local | Vehicles/second |
|---|---|---|---|
| Center | 1 | Áurea Pinheiro Street | 25/60 s |
| Center | 2 | Bus Station of Miguel Pereira | 25/60 s |
| Peripheric | 3 | Javary Lake | 2/60 s |
| Peripheric | 4 | São Roque Street | 1/60 s |

At each sampling point, five trees were selected. The criteria for selection of the trees were: maximum distance of 10 meters between them, healthy, without damage and without paint on the base or trunk, with thickness ≥ 0.2 m², with barks with similar characteristics and with the existence of lichen to their surface to ensure the homogeneity of the samples.

The collections for the quantitative-qualitative analyses were made through seasonal campaigns during the period January to October / 2017, using a sampling grid, according to the methods of Kovács (1992), Poggiani et al. (1996) and Asta et al. (2002) adapted to this study. The sample size of the author's own production measures 0.2 m x 0.2 m and is subdivided into 100 squares of 4 x 10-4 m² (Figure 1). Following the orientation of a magnetic compass, the sampling grid was superimposed on the east face of each chosen tree, 1.2 m from the ground.

*Figure 1: Sampling grid.*

**2.3 Quantitative and qualitative analysis**

The identification of the species within the sampling grid, as well as of the morphofunctional groups was made through observation (with the aid of a hand magnifying glass) in the lichen stalk, using identification keys, taking into account characteristics as habit (adherence to substrate), format, coloration and size according to the CNALH - Consortium of North American Lichen Herbaria.

For the analysis of the qualitative data, an inventory of the species of lichens was elaborated, and a survey of their specific richness was made, referring to the total number of species present in the squares distributed in the trees, per campaign.

The quantitative temporal variation of the species was analyzed using seasonal sampling, between January and October 2017, using the grid of 0.04 m² (subdivisions = 100 reticles), along the sampling points. The phytosociological method was related to quantitative data such as absolute frequency and coverage of the lichen species arranged within the grid area.

The survey of the relative coverage of the species in the sampling grid was performed according to the method of Poggiani et al. (1996), which is based on the use of a reticulated square, subdivided into 100 reticles, where the number of occupied reticles is counted.

The data collected were applied to Equations 1, 2 and 3 and tabulated in the Microsoft Excel ® program.

$$IAP = \sum \left(\frac{Qi \times fi}{n} \times c_i\right) \tag{1}$$

In this formula, (IAP) is the index of atmospheric purity of the season; (n) is the number of forophytes sampled at the station; (Qi) is a specific ecological index of species I; (fi) is the absolute frequency of the species I at the station; (Ci) is the relative coverage of the species I in the season; (A) is absolute frequency; is expressed by Equation 2:

$$FAi = \left(\frac{u_i}{u_t}\right) \tag{2}$$

In this formula, (FAi) corresponds to the absolute frequency of the species I; (ui) is the number of sample units (forophytes) at the station in which species I occurs; (ut) is the total number of sampling units (forophytes) of the station.

The specific ecological index (Qi) is related to the resistivity/sensitivity of a particular species, corresponding to the average number of species that coexist with this species in the indicated station and is expressed by Equation 3.

$$Qi = \sum \left(\frac{Aj-1}{Nj}\right) \tag{3}$$

Where (Aj) corresponds to the number of species present in each season where the species I is located; (Nj) corresponds to the number of sample units in which the species I is located.
The final Index of Atmospheric Purity (IAP) of each collection point was obtained by the average of the IAPs per campaign (seasonal period). After calculating the average IAP of each sampling point, the air received a qualification, according to Table 2, adapted from Conti (2008).

*Table 2: Quality levels of the Index of Atmospheric Purity (IAP)*

| Level | IAP | Air quality | Pollution level |
|---|---|---|---|
| A | 0 ≤ IAP ≤ 10 | Bad | High |
| B | 10 < IAP ≤ 20 | Regular | Moderate |
| C | 20 < IAP ≤ 30 | Good | Low |
| D | IAP > 30 | Great | Very low |

## 3. Results

21 taxa of lichens were recorded, distributed in 09 families and 13 genera, according to the morphofunctional groups, in the sampled sites (Table 3).
In points 1 and 2, located in the central area of the city, it was observed that the specific richness was represented by the total of 10 and 11 species, respectively; while in points 3 and 4, the specific richness corresponded to the total 15 and 14 species in each point, respectively. The species *Ramalina celastri*, of the family Ramalinaceae, as well as Leptogium sp., belonging to the Collemataceae family, was registered only in P3 (Table 3). These species were identified as sensitive to atmospheric pollution, in the study conducted by Estrabou et al. (2011) in Argentina, which corroborates the idea that the less urbanized sites, because they are less passive to air pollution, shelter more sensitive species.
On the other hand, the species *Physcia* sp., of the Caliciaceae family, was only identified in forophytes located in the city's bus station-point 2 (Table 3). Estrabou et al. (2011) also studied this species of lyquenized fungus, and identified it as being resistant to pollution in the city of Córdoba, Argentina.

*Table 3: Inventory of species identified in the samples*

| Habit | Family | Species | Point 1 | Point 2 | Point 3 | Point 4 |
|---|---|---|---|---|---|---|
| Crustose | Teloschistaceae | Caloplaca crocea | | | | x |
| | Collemataceae | Collema sp. | | | x | |
| | Arthoniaceae | Cryptothecia rubrocincta | | | | x |
| | Arthoniaceae | Cryptothecia sp1 | x | x | x | x |
| | Arthoniaceae | Cryptothecia sp2 | x | x | x | x |
| | Graphidaceae | Graphis sp. | | | x | x |
| Foliose | Candelariaceae | Candelaria concolor | x | x | x | x |
| | Ramalinaceae | Crocynia pyxinoides | x | | | |
| | Collemataceae | Leptogium sp. | | | x | x |
| | Parmeliaceae | Canopermelia texana | x | x | x | x |
| | Parmeliaceae | Parmotrema sp. | x | x | x | x |
| | Parmeliaceae | Parmotrema superaguiense | | | x | |
| | Parmeliaceae | Parmotrema tinctorum | x | x | x | x |
| | Caliciaceae | Physcia sp. | | x | | |
| | Caliciaceae | Pyxine sp1 | x | x | x | x |
| | Caliciaceae | Pyxine sp2 | x | x | x | x |
| | Caliciaceae | Pyxine sp3 | | x | x | |
| | Caliciaceae | Pyxine berteriana | x | | | x |
| Fruticose | Ramalinaceae | Ramalina celastri | | | x | |
| | Ramalinaceae | Ramalina peruviana | | | | x |
| | Teloschistaceae | Teloschistes sp. | | x | x | |

Only in São Roque street (point 4) the presence of the species *Cryptothecia rubrocincta* – Table 3 was noted. Although lichens with a crustose habit are cited in the literature as the most resistant to atmospheric pollution, it is valid not to generalize this condition. In a study conducted by Martins et al. (2008), where lichens were used as bioindicators to verify air quality in a thermoelectric area in Rio Grande do Sul (Brazil), the species *Cryptothecia rubrocincta*, of a crustose habit, was registered, only in the sampling area that showed higher values of richness and diversity. This species also occurs in environmental preservation areas in the state of Pernambuco (Brazil) as well as in the Ecological Reserve of Gurjaú and in RPPN Frei Caneca, suggesting that this species develops better in environments where anthropic interference is in a less scale (Pereira et al., 2006).

It is notorious the resistivity described by Estrabou et al. (2011) of the species Candelaria concolor, it is present in all sampling stations, including those where there is greater traffic of motor vehicles (Table 3).

The genera Pyxine and Canopermelia were recorded in points 1, 2, 3 and 4. According to Käffer (2011), species of these genera occur with high frequency in several regions of Brazil. Like the genus Carnopermelia, species of the genus Parmotrema are abundant in Brazil and therefore are among the most used as bioindicators of air quality in national studies, especially *Parmotrema tinctorum* due to the ease of its Identification (Vaz, 2012), this species was recorded in the four sampling stations as shown in Table 3.

The IAP values found for each sampled point are shown in Figure 2, being point 4 – São Roque street, the point with the highest value of IAP (31.45) and point 1 – Áurea Pinheiro street, the lowest value of IAP (7.91).

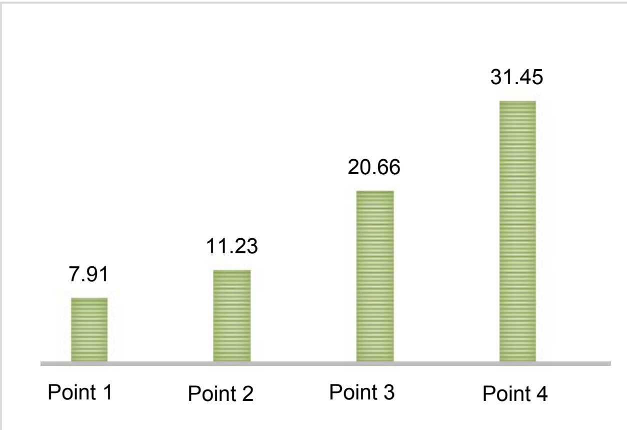


*Figure 2: IAP per sampling point.*

According to the air quality of each sampling station, reproduced in Table 4, it is noted that in the points where there is greater urbanization (point 1 – Área Pinheiro street and point 2 – Bus Station of Miguel Pereira) the air quality, according to IAP, was framed as bad and regular, respectively. In the places with residential areas, where there is lower flow of automotive vehicles, the air quality was better, being framed as good (point 3 – Javary lake) and optimum (point 4 – São Roque street).

*Table 4: Air quality according to IAP*

| Point | IAP | Air quality | Pollution level |
|---|---|---|---|
| 1 | 7.91 | Bad | High |
| 2 | 11.23 | Regular | Moderate |
| 3 | 20.66 | Good | Low |
| 4 | 31.45 | Great | Very low |

## 4. Conclusions

In this study it can be concluded that the point presence of bioindicator species *Ramalina Celastri* and *Leptogium* sp, described in the literature due to its high sensitivity to air pollutants, corroborates with the idea that in points located in the peripheric area (points 3 and 4), that is, more distant from the center, have a lower incidence of air pollution. On the other hand, in places where vehicle traffic is intense, as in the Bus Station, the incidence of air pollution is higher, since the bioindicator species *Physcia* sp., identified by other authors as resistant, was only recorded at this point.

The survey of IAP – Index of Atmospheric Purity, besides being simple and economically viable, proved to be an efficient methodology in detecting and monitoring air pollution, by fulfilling its objective of revealing the diagnosis of atmospheric quality of sampled points. Moreover, we observed the alignment and coherence of the results obtained from IAP with inferences from the survey of the species, such as São Roque street (point 4) that presented the second highest value of specific richness and, in parallel, optimal air qualification (higher average value of IAP - 31.45) ratifying the relationship that the less urbanized, the higher the quality of the atmospheric at the site.

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