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# BIOMONITORING OF LICHEN AS A BIOINDICATOR OF ATMOSPHERE QUALITY IN ULAANBAATAR, MONGOLIA

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***Abstract:*** *The lichen species are an essential part of plant diversity and they are well-established indicators of air pollution. Lichen is used to indicate different levels of nitrogen pollution and as indicators of forest continuity City of Ulaanbaatar, the capital of Mongolia was initially designed for a half million residents. Due to intense rural-to-urban migration after transition to market driven economy, the population of the capital is nearly tripled, which resulted in huge area of informal settlements and elevated number of vehicles. Tents and small buildings in above settlements heated by conventional stoves by burning coal and wood, while the most vehicles on the road are imported second-hand cars. During last two decades, air quality of capital city Ulaanbaatar is considered as an emerging issue and above two are primary sources of outdoor air pollution. The most abundant air pollutants are nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$) and carbon monoxide (CO) which have disastrous effects on health when inhaled over prolonged periods of time. Due to the quantities of these pollutants would be far more abundant and thus cause the catastrophic effects to the air quality that is seen in Ulaanbaatar. Various techniques have been developed to monitor air quality, including biomonitoring using lichens. In this study, we monitored types of epiphytic lichens covering sensitive to air pollution fruticose type and relatively tolerant foliose type of lichens. Unlike air quality index, lichens clearly show negative impact of poor air quality on surrounding ecosystems. We examined lichens on Larix sibirica, themost abundant coniferous tree of the area. Both foliose and fruticose types of lichens are abundant in Larix sibirica dominated forests located to the northern areas of Ulaanbaatar. It indicates the area is free of pollution. In contrary, fruticose type lichens, especially representatives from the genera Usnea, Cladonia and Vulpicidia are absent in coniferous forest to the southern areas of Ulaanbaatar.*

**Keywords:** *lichen species, Ulaanbaatar, Mongolia, air pollution, bi indicators*

## INTRODUCTION

Lichens are mutualistic associations of a fungus and an algae or cyanobacteria. In nature, they occur on rocks, bare grounds, and trees, the latter known as epiphytic lichens. Due to their dependence on airborne nutrients, lichens are very sensitive to air pollution especially to sulfur dioxide. They do not bear defensive tissue, therefore quickly absorb, and accumulate sulfur dioxide in their tissue, which subsequently leads to a damage of chlorophyll in phycobiont algae so that photosynthesis is inhibited. Because of this sensitive characteristic, lichens are widely used as environmental indicators or bioindicators. Depending on their degree of tolerance, some species may present with certain concentration of pollutants, while all species mayvanish with extremely poor air quality. On this ground, lichens provide a relevant, sensitive, and measurable indicator for long-term monitoring (Das *et al*., 2013; Giordani, 2007).
One of the places where lichens could be used as bioindicator is city of Ulaanbaatar, the capital of Mongolia. The city is characterized by its high elevation (1350 meters above sea level), low precipitation (200-300

mm), and its location in a basin (Hauck, 2008). The city was initially designed for a half million residents. However, due to 1990s intense rural-to-urban migration, population of the capital was far more exceeded than its infrastructure capacity and ended up with informal settlements or huge ger areas (Figure 1). Since Ulaanbaatar is the coldest capital in the world with annual mean temperature of minus 3.7ºC (Hilbig et al., 2004), the major cause (c.a. 80%) of air pollution comes from coal burning stoves which are the sole way to heat ger homes under sub-zero temperatures. There are 130.5 thousand families in ger areas burn roughly 525 thousand metric tonnes of coals, 290 thousand cubic metres of firewood, and other combustible materials each year (http://agaar.mn/static/stove-distribution).
As a result, concentrations of the major pollutants far outreached the guideline values provided by World Health Organization (WHO). For example, on the coldest days of the year, daily average of $PM_{2.5}$ level reaches 687 $\mu g/m^3$, which is 27 times higher than the level WHO recommends as safe (https://www.unicef.org/mongolia/environment-air-pollution).

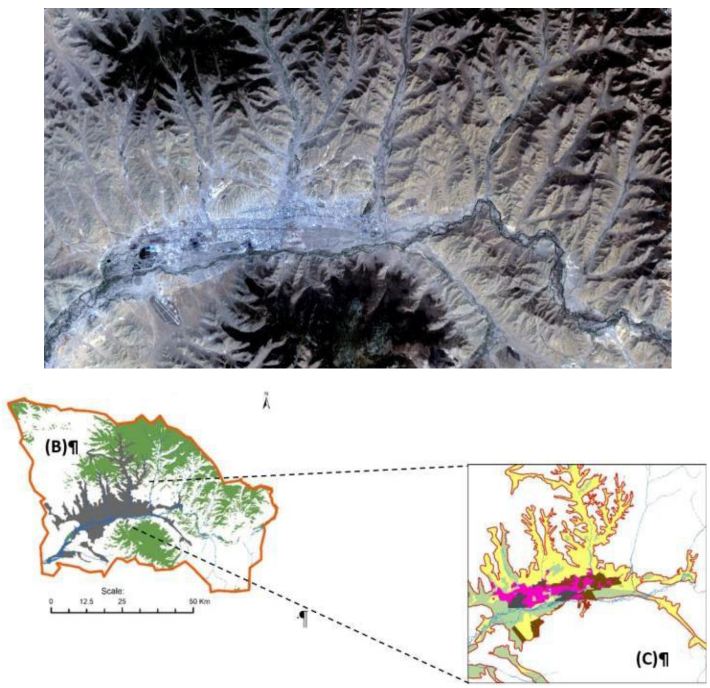



Figure 1. Map of the city of Ulaanbaatar
(A) Landsat image (https://landsat.visibleearth.nasa.gov); (B) Settlement areas of the city, where grey - settlement areas, green –forest areas, and blue – rivers; (C) Land use map as of 2010, where yellow – ger areas (Myagmartseren et al., 2018)

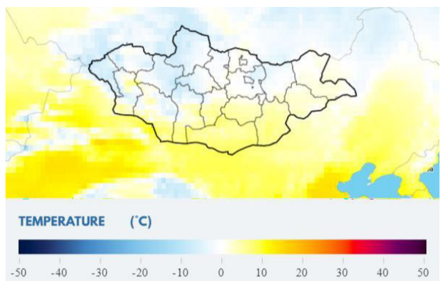
Similarly, sulphur dioxide, the major pollutant from coal burning reaches 170 $\mu g/m^3$, which is eight times higher than a national air quality standard. The second major source (10%) of air pollution is 340 thousand vehicles on the road and most of which are (79%) aged more than ten years and with substandard quality. Total of three thermal power plants are responsible for 6% of Ulaanbaatar air pollution, and the rest 4% is windblown dust (Davy et al., 2011).
Supporting reason for dense air pollution of Ulaanbaatar is its geographical location in a basin. The city is located along the Valley of Tuul River. Surrounding mountains reduce vertical and horizontal dispersion of air pollutants, especially during wintertime (Figure 1).

**Objectives**
Polluted air accumulates in the city area and shows number of negative impacts on human and ecosystem health. Air quality of capital city Ulaanbaatar is considered as an emerging issue and dozens of measures taken during the last two decades; however, no significant improvements have been achieved so far. Study

on lichens in relation with air quality started in mid 90s (Galsan et al., 1995; Enkhtuya, 1999) and further studies examined Ulaanbaatar air pollution effect on lichenous flora of surrounding ecosystems, biochemical and chemical analysis of lichens, bioindicator roles of local lichens and biodiversity of lichens (Ganbold et al., 2007; Hauck, 2008; Baljinnyam et al., 2009; Delgermaa et al., 2016).
In this study, I examined epiphytic lichens on *Larix sibirica*, the most abundant tree of the local forest at four sites close to Ulaanbaatar city. Two sites were chosen from Bogd Khan Mountain to the south and downwind of the city and two were from Chinggeltei Mountain to the north and upwind of the city.

## Climate Change in Mongolia

**Temperature:** Very high rates of historical warming are reported in recent years. Average temperatures rose by average of 2.41°C between 1940 and 2017. It is mainly associated with reduced cold days and increase in hot summer days. During that time the maximum temperature has risen up to 2.6°C while the minimum has risen only up to 0.3° around the same time. According to the research the temperature trends can be different depending on the area, altitude and biome.



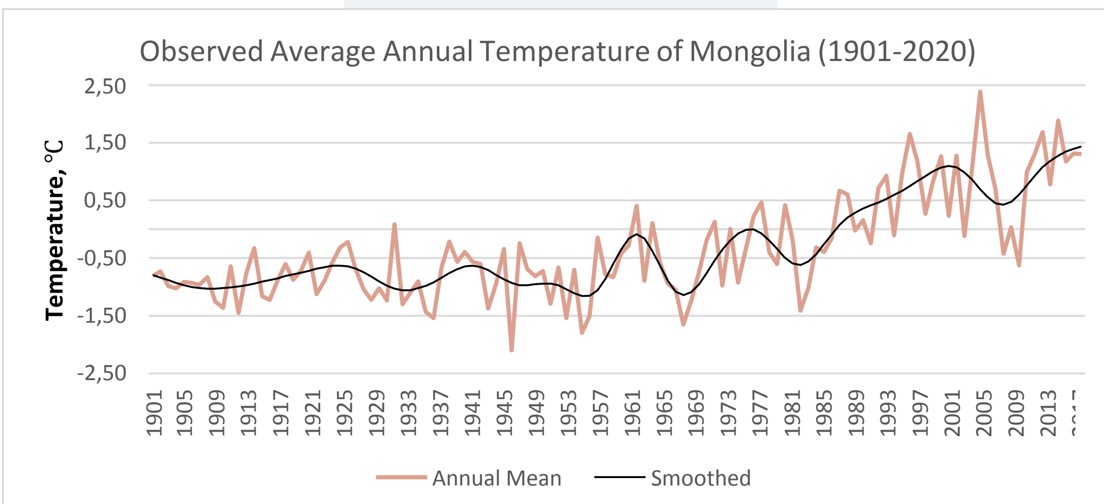




Figure 2. Observed Average Annual Temperature of Mongolia for 1901-2020 (https://1212.mn)

**Presipitation**: During the period of 1940 to 2017 it is reported a decline in average annual precipitation of 7% to the Mongolia's Third National Communication. The central regions of the country have observed this decline in strong rainfalls over time. This supports the large increase in winter snowfall. Also during the time of 1971 until 2017 it is believed the number of consistent wet days and days with heavy precipitation have dropped. But, these claims have low statistical importance and should be negotiated carefully. Locals observation and knowledge have identified an increase in occurring thunderstorms and short high rainfall events

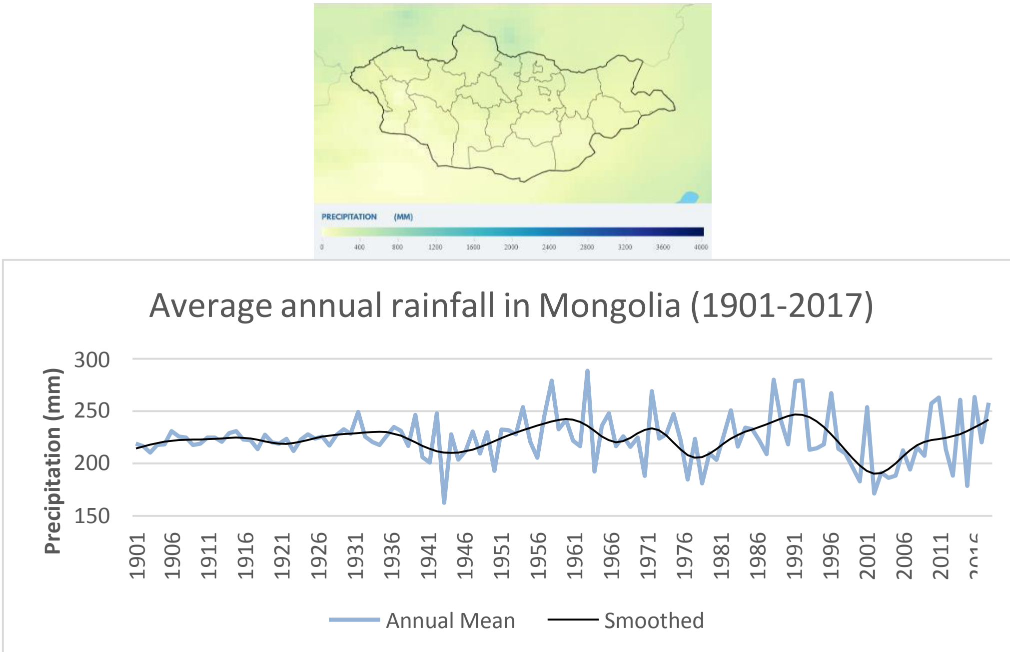



Figure 3. Observed Average Annual Rainfall of Mongolia for 1901-2020 (https://1212.mn)

**Drought and Dust:** Mongolia is affected by two types of droughts. Meteorological (associated with a difference of precipitation) and hydrological (associated with a difference in surface and subsurface water flow, originating mainly in the regions wide river basins.) Today, Mongolia is expected to have severe meteorological drought around 4%, according to standardized precipitation evaporation index (SPEI) of less than -2. In spite of that, Mongolia is prone to other complex forms of drought mainly due to its unique climate parameters. Dry and hot summers followed by cold winters that create a natural hazard named "Dzud". The study also shows an increase in the frequency of both meteorological and pasture drought from 1965-2010. It is widely supported and confirmed by the local knowledge and observations, due to this in drier areas, frequency of dust storms has increased.

**Air Pollution:** Firstly, it should be stated that the air pollution is a top priority issue for the government, and its monitoring is very important for the public health. Until 2006, the capital city, Ulaanbaatar had four air quality monitoring stations and 15 mobile stations for controlling purposes. These four stations mainly located in the internal parts of the capital city only measured sulfur dioxide (SO2) and nitrogen oxides ($NO_2$) concentrations (Figure 4). The studies from the monitoring data indicates the rise in the $SO_2$ and $NO_2$ concentration during the year 2013-2015.
However, $SO_2$ pollution, which has sources similar to $PM_{10}$, authorizes a direct linkage to growing trend in coal use. Likewise, increasing vehicular population is one of the main causes for increased $NO_2$ levels, a primary precursor for ground-level ozone pollution and secondary contributor to $PM_{2.5}$ pollution (Guttikunda et al., 2013). It could be seen that the 4 stations and their capabilities were insufficient to cover a large area and conduct thorough air pollution related studies.

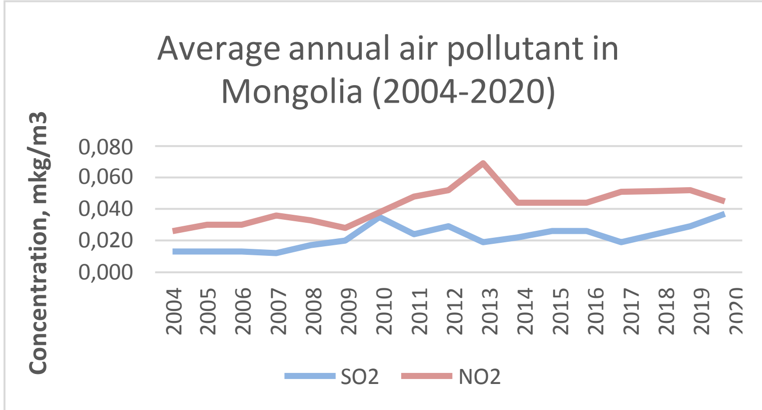



Figure 4. Concentration of $SO_2$ and $NO_2$

## MATERIALS AND METHODS

### Study sites

Total four sites were selected in this study. Site A and B located in Bogd Khan Mountain area which is to the south and downwind of the city. The Site A located at 1762 meters above sea level, where wind flows mostly from the west, rather not from the city. Site B was just 1.62 kilometers apart from Site A, however 298 meters below and located downwind the emission from Thermal Power Plant III. With this reason, the Site B was suspected as the most polluted site along with other three sites (Figure 5). Site C and D were from Chinggeltei Mountain to the northern side and mostly upwind of the city. The Site C was chosen because its location along the Selbe River. During winter, when air pollution reaches its highest peak, the polluted air fills up the valley and reaches Site C if wind flow is weak. That is why we suspect this site to expose to mild pollution. The last Site D was chosen because its distance from the source of pollution. All of the above four sites belonged to the same type of forest or coniferous forest where larch tree dominates (Figure 5). Details of the selected sites were given in Table 1.

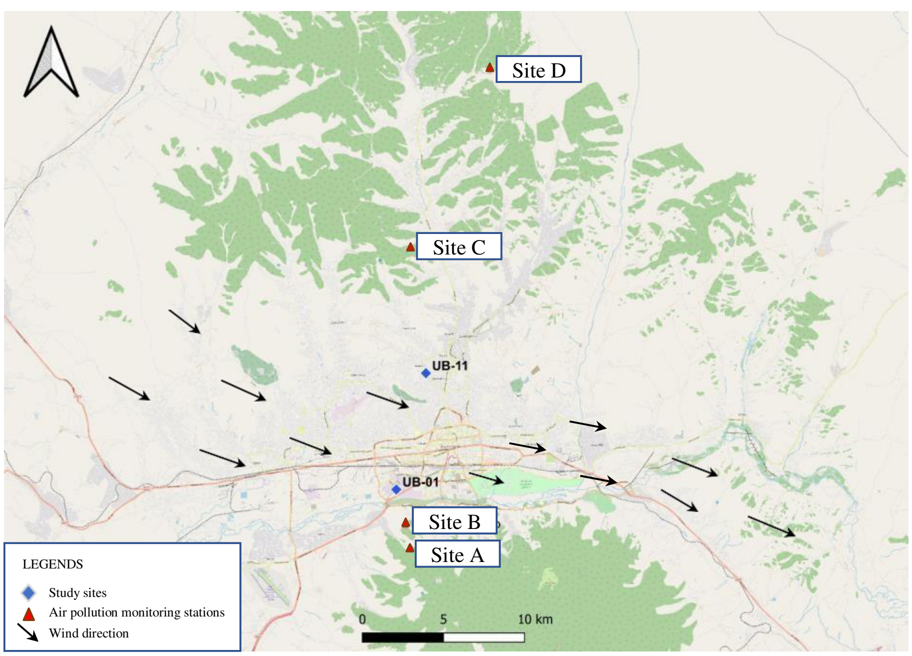



Figure 5. Location of the selected sites

Table 1. Details of the selected sites

| Site of study | Bogd Khan Mountain (downwind the city) | | Chinggeltei Mountain (upwind the city) | |
|---|---|---|---|---|
| | Zaisan | Khiimoriin ovoo | Yargait | Khandgait |
| | Site A | Site B | Site C | Site D |
| Latitude | 47º86′26.2″N | 47º87′61.5″N | 48º02′93.9″N | 48º12′71.2″N |
| Longitude | 106º88′28.6″E | 106º87′91.7″E | 106º88′90.8″E | 106º95′85.8″E |
| Altitude | 1782 m | 1464 m | 1545 m | 1731 m |
| Distance from city center by road or path | 8.6 km | 7.0 km | 14.7 km | 26.9 km |
| Forest type | Coniferous | Coniferous | Coniferous | Coniferous |

**Lichen sampling**

Siberian larch *Larix sibirica* was used in this study because of its abundance and morphological characteristics of bark that is rough and suitable for lichen settling. Lichen colonies were collected with the help of forceps, placed in sample bags and transferred to a laboratory.

**Identification of lichens**

Lichen specimen was collected in polyethylene bags and transferred to a laboratory. The samples were air dried and identified using light microscopy with the help of chemical tests (Orange et al., 2010).

**Total lichen coverage**

Total fifteen individual larch trees, whose diameters ≥20 cm were selected at each site. Quantification of lichens was done by placing a lichen grid (20X20 cm) on the tree at 0-20 cm and 130-150 cm heights from ground level (Figure 7).

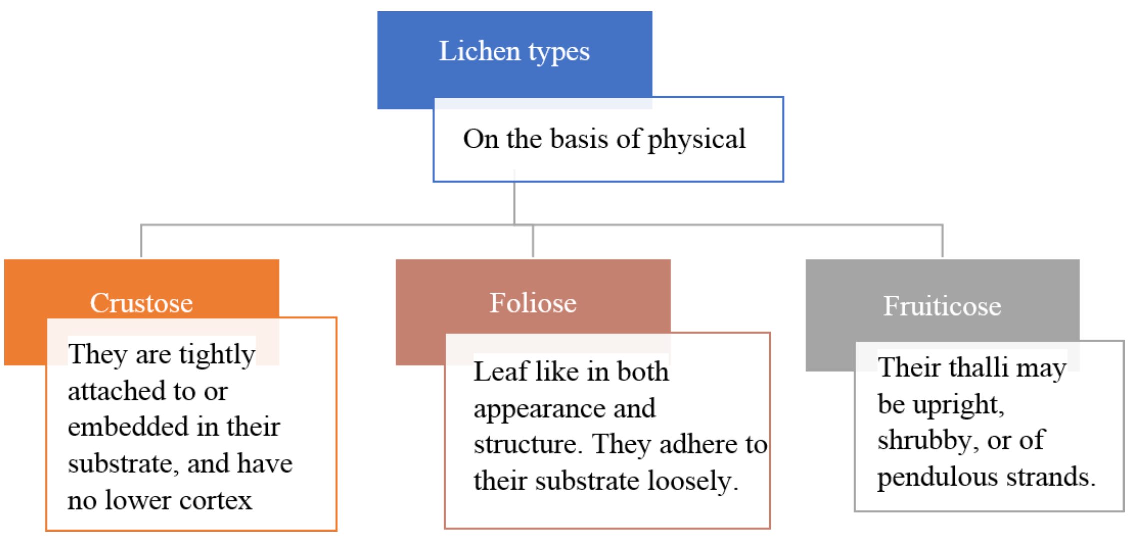



Figure 6. Lichen types

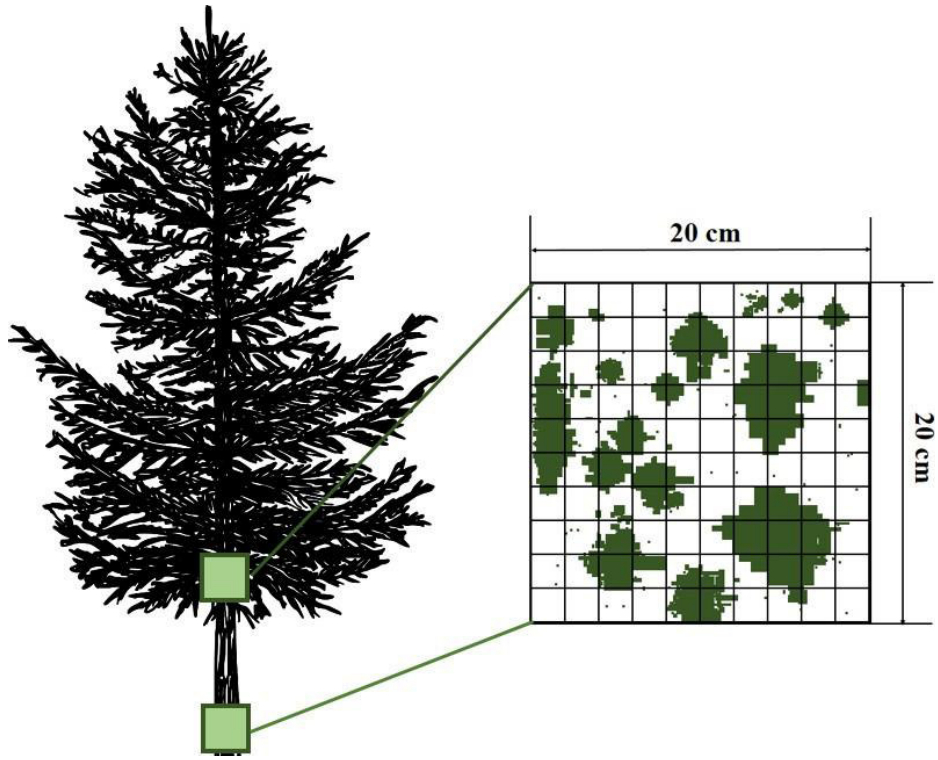



Figure 7. Lichen grid (20cm*20cm)

## RESULTS AND DISCUSSIONS

### Lichen diversity

Currently there are 225 species of lichen recorded in Bogd Khan Mountain (Enkhtuya, 2007). However, in this study, we recorded collectively 12 lichen species at the A and B sites selected from Bogd KhanMountain area (Table 2); 10 and 8 species from the Site A and B, respectively.

Most lichens observed from Bogd Khan Mountain belonged to foliose and crustose growth type which are relatively tolerant to air pollution. For example, according to Hawksworth, 1970, foliose type lichen *Hypogymnia physodes* could tolerate 70µg/m$^3$ mean winter $SO_2$ concentration and appear around the basis of the trees, but do not extend up the trunks.

In our study, mostly all sensitive species from fruticose type lichens were vanished and foliose type species - *Hypogymnia physodes, Flavopunctelia soredica and Parmelia sulcata* were observed as dominant lichens mostly around the basis of the trees. Especially, two tolerant species *Flavopunctelia soredica* and *Parmelia sulcata* comprised more than 90% of the total lichen coverage at the Site B.

From fruticose growth type, only one species - *Evernia mesomorpha* was observed in this area. To note, only one colony of *Evernia mesomorpha* was recorded among fifteen larch trees used at the Site B.

For the two sites C and D from Chinggeltei Mountain area, upwind the city, the most sensitive fruticose type lichen species were observed as abundant lichens (Table 2).

Well known bio-indicator species from a genus *Usnea*, which exist when mean winter sulfur dioxide concentration is below 40µg/m$^3$ only were observed at both Sites C and D. Furthermore, golden-colored foliose type lichen *Vulpicidia pinastri*, which is extremely sensitive to any type of air pollution was recorded at Site D. This result indicated an excellent air quality at this site.

We collected and identified total 22 species of lichens from Chinggeltei area; 15 and 22 species from the Site D and C, respectively. Some of the lichens were photographed and shown in Table 3.

Table 2. Lichen species recorded at each study site

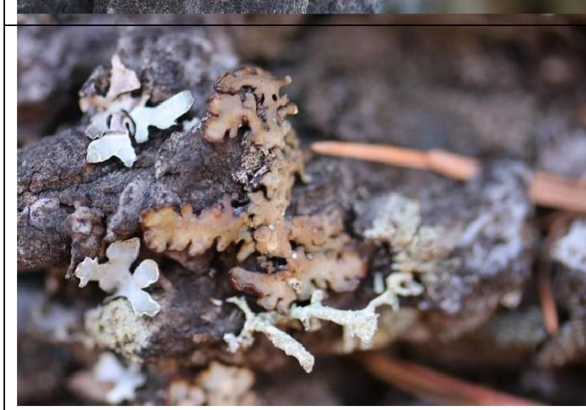
| Species | Morphology | Bogd Khan Mountain | | Chinggeltei Mountain | |
|---|---|---|---|---|---|
| | | Site A | Site B | Site C | Site D |
| *Cladonia coniocraea* | Fruticose | | | + | + |
| *Cladonia fimbriata* | Fruticose | | | + | + |
| *Evernia mesomorpha* | Fruticose | + | + | + | + |
| *Usnea fulvoreagens* | Fruticose | | | + | + |
| *Usnea hirta* | Fruticose | | | + | + |
| *Usnea lapponica* | Fruticose | | | | + |
| *Usnea* sp. | Fruticose | | | | + |
| *Flavopunctelia soredica* | Foliose | + | + | + | + |
| *Hypogymnia bitterii* | Foliose | + | | + | + |
| *Hypogymnia physodes* | Foliose | + | + | + | + |
| *Melanelia exasperatula* | Foliose | + | | | + |
| *Melanelia olivacea* | Foliose | | | + | + |
| *Parmelia soredica* | Foliose | | + | + | + |
| *Parmelia sulcata* | Foliose | + | + | + | + |
| *Vulpicidia pinastri* | Foliose | | | | + |
| *Buellia* sp. | Crustose | | | + | + |
| *Lecanora piniperda* | Crustose | + | | | + |
| *Lecanora symmicta* | Crustose | | | + | + |
| *Lepraria sp* | Crustose | + | | | + |
| *Rinodina* sp. | Crustose | | | + | + |
| *Trapeliopsis flexuosa* | Crustose | + | + | + | + |
| *Trapeliopsis granulosa* | Crustose | | + | | + |
| *Hypocenomyce scalaris* | Squamulose | + | + | | |
| | **Total** | **10** | **8** | **15** | **22** |

+ present

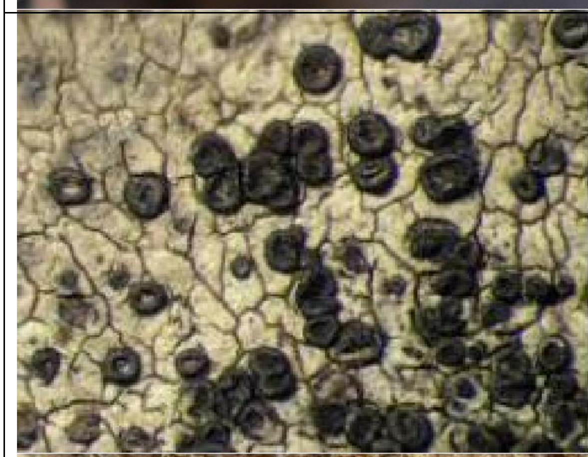
Table 3. Lichen species observed near Ulaanbaatar city

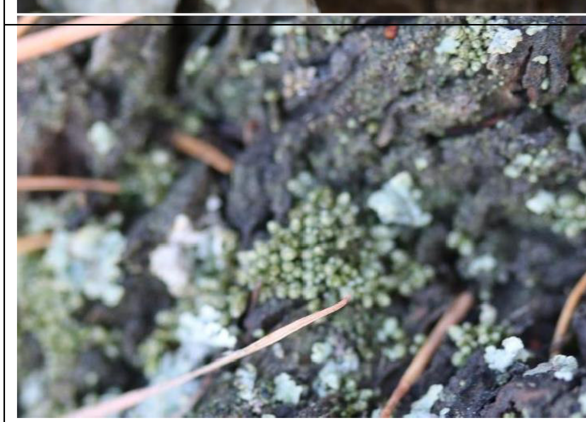
| | | |
|---|---|---|
|  | Fruticose | *Cladonia coniocraea* |

| | | |
|---|---|---|
|  | Fruticose | *Cladonia fimbriata* |
|  | Fruticose | *Evernia mesomorpha* |
|  | Fruticose | *Usnea fulvoreagens* |
|  | Fruticose | *Usnea hirta* |

| | | |
|---|---|---|
|  | Fruticose | *Usnea lapponica* |
|  | Fruticose | *Usnea* sp. |
|  | Foliose | *Flavopunctelia soredica* |
|  | Foliose | *Hypogymnia bitterii* |

| | | |
|---|---|---|
|  | Foliose | *Hypogymnia physodes* |
|  | Foliose | *Melanelia exasperatula* |
|  | Foliose | *Melanelia olivacea* |
|  | Foliose | *Parmelia soredica* |

| | | |
|---|---|---|
|  | Foliose | *Parmelia sulcata* |
|  | Foliose | *Vulpicidia pinastri* |
|  | Crustose | *Buellia* sp. |
|  | Crustose | *Lecanora piniperda* |

| | | |
|---|---|---|
|  | Crustose | *Lecanora symmicta* |
|  | Crustose | *Lepraria sp* |
|  | Crustose | *Rinodina* sp. |
|  | Crustose | *Trapeliopsis flexuosa* |

| | | |
|---|---|---|
|  | Crustose | *Trapeliopsis granulosa* |
|  | Squamulose | *Hypocenomyce scalaris* |

**Total lichen coverage**

Total lichen coverage at each sites were calculated on the basis of data obtained from fifteen trees. It means total sixty larch trees used in this study. And a column graph was plotted and shown in Figure 8. The highest lichen coverage was observed at Site A, both for 0-20 cm and 130-150 cm heights above ground level. Lowest coverage rate was observed at Site B, where emissions from Thermal Power Plant III sediment. A previous finding (Enkhtuya, 2007) proved that high amount of heavy metals were accumulated in tissue samples of the lichens at this site.

At the Site C and D, coverage difference between the heights from ground level is reduced. This result indicates that environmental condition at these sites is more favorable and lichen species extend to the trunk of the trees.

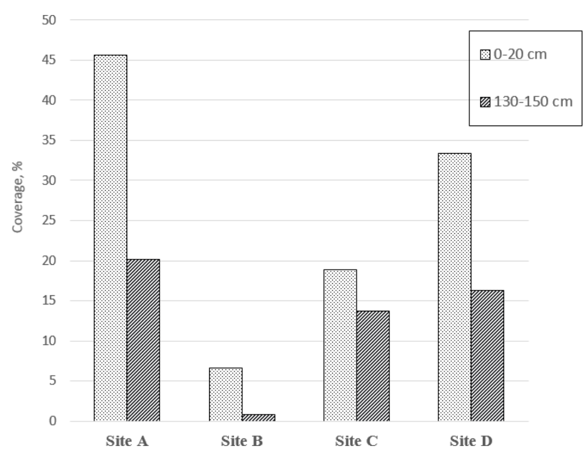



Figure 8. Total lichen coverage at the selected study sites


Figure 9: Lichen coverage in selected sites (0-20cm)


Figure 10: Lichen coverage in selected sites (130-150cm)

**Lichens as bioindicator of air quality**

Sulfur dioxide level in the air can be estimated qualitatively by studying the epiphytic lichens growing on trees (Hawksworth, 1970). In contrary, higher vascular plants and trees respond to air pollution at much slower rate (Muir et al., 1988). I observed lichen diversity within and outside of the city of Ulaanbaatar. All species of the trees and bushes near roads, parks and residential areas of Ulaanbaatar city do not bear any of the species of lichens. This result simply suggests a disastrous amount of air pollution that is mean winter sulfur dioxide concentration is around or exceeded 170μg/m$^3$. This finding also meets measurement results from the air quality monitoring stations.

Bogd Khan Mountain area, downwind of the city bear only lichen species tolerant to mild pollution, but size, color and morphology are already changed, and this result indicate plant stress under polluted conditions (Figure 11).

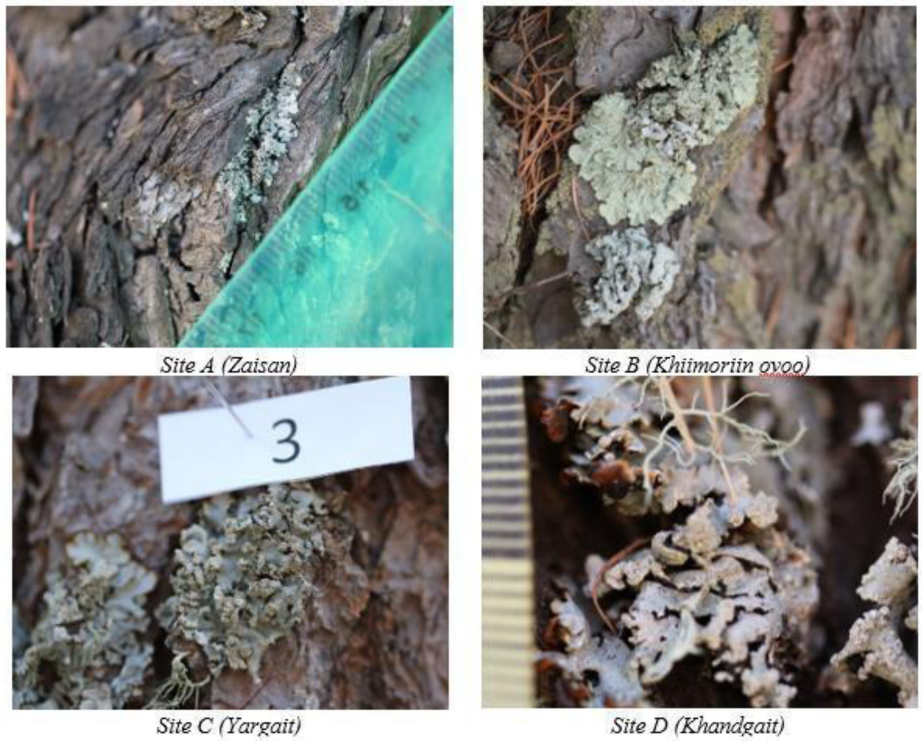



Figure 11: Morphological difference of *Hypogymnia physodes* in selected sites

**CONCLUSION**

In this study we observed clear change in lichen diversity downwind and upwind of the capital cityUlaanbaatar. The results suggest that polluted air generated from conventional stoves from ger areas transferred to the southern part of the city and show its negative impact to Bogd Khan Mountain ecosystems.Lichens are the first organisms respond to environmental pollution and warn us; but if such antropogenic false activity still remains for the future, many other important life forms may degrade in term of prolonged exposure time

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