Monitoring of recreational areas of Yuzhno-Sakhalinsk and its surroundings

V V Kaganov¹²³, A V Kordukov²³ and A K Ezhkin²⁴
¹Sakhalin Branch of the Botanical Garden-Institute FEB RAS, Yuzhno-Sakhalinsk, Russia
²Institute of Marine Geology and Geophysics FEB RAS, Yuzhno-Sakhalinsk, Russia
³«Magnolia Park», LLC, Yuzhno-Sakhalinsk, Russia
⁴Botanical Garden-Institute FEB RAS, Vladivostok, Russia
E-mail: a.kordyukov@imgg.ru

Abstract. This paper presents the results of the study of lichens in Yuzhno-Sakhalinsk and its surroundings. To assess the epiphytic cover the method of occurrence measuring on the tree trunks with the help of a frame 10×40 cm (400 cm²) was used at 15 locations within the study region. Zones and exposure gradient were defined through clustering and ordination method. 47 species of epiphytic lichens and their distribution characteristics in various areas of human impact were identified.

1. Introduction

*Populus maximowiczii* A. Henri is abundant in Yuzhno-Sakhalinsk urban vegetation. The presence of this phorophyte in both natural and artificial landscapes gives a good opportunity to assess and compare epiphytic lichen cover in the same study area which is one of the basic conditions for epiphytic lichen monitoring [1].

2. Study Region

Territorially the study took place in Yuzhno-Sakhalinsk, its surroundings and the valley of Belaya river (Sokol settlement of the Dolinsk District). Yuzhno-Sakhalinsk is situated in the southeast of the Sakhalin Island in the central part of Susunaiskaya lowland elongated longitudinally between the Susunaiskiy and the Mitsulskiy ridges.

The region is a part of Yuzhno-Sakhalinsk climate area which is characterized by moist monsoon climate, significant (about 860 mm annually) amount of precipitation, warm souths winds in summer and cold north and northwest winds in winter. Average annual temperature is 2-3 °C with average minimum of −13.5 °C in January and average maximum of 17.2°C in August. Considerable cloudiness and frequent mists account for chilly and moist nature of the climate [2].

Climate conditions and specific geographic location (the city is located in the lowland surrounded by mountain ridges, frequent atmospheric inversions) prevent dispersal and removal of harmful substances supplied to the atmosphere from various sources (road and rail transport, coal-burning boilers, etc.). As a result a thick layer of smog is formed which tends to “hang” in lower atmosphere for a long time. Due to sustained and continuous contamination of the city as well as anthropogenic
transformation of natural vegetation in the suburbs the urban lichen biota is characterized by species tolerant to atmospheric pollution [3].

3. Materials and Methods
This study addressed the specifics of epiphytic lichen distribution if different conditions of human-induced impact. In urban area 5 plots were set up in public gardens located along public roads in vicinity to intersections of major city roads: Sakhalinskaya street – Mira avenue, Lenina – Pogranichnaya streets, Lenina street – Pobedy avenue, Komsomolskaya – Sakhalinskaya streets. In Municipal Park named after Y.A. Gagarin 4 plots were set up. Plots remote from major public roads: territory of the Institute for Marine Geology and Geophysics of the Far East Branch of the Russian Academy of Science, flood plains along Krasnoselskaya, Rogatka, Belaya rivers – 5 plots. Control plots are shown in Figure 1.

The study of the lichen cover was performed during the summer of 2018 in two stages:
1. reconnaissance operations including set up of test plots and gathering of herbarial materials for further identification;
2. measuring parameters of lichen cover.

Sample trees on which the condition of the lichen cover was assessed were selected to be of the same diameter, at least 10 trees in the plot, without inclination relative to the ground or with inclination not exceeding 10°. To assess the condition of the lichen cover the number of species and occurrence were measured. The frame 10×40 cm (400 cm²) divided into 4 parts: microareas (10×10 cm), was used to measure occurrence. The frame was applied to four sides of a tree trunk at height from 1,1 to 1,5 m. The total of 2400 microareas was measured in the study region.

The biological diversity of lichens was assessed on the basis of Shannon diversity index (1) (Shannon, 1963) and Pielou’s evenness index (2) (Pielou, 1966, 1975):

\[ H = - \sum_{i=1}^{S} \frac{n_i}{N} \log_a \frac{n_i}{N} \]  

\[ E = \frac{H}{H_{max}} \]

where:
H – Shannon index, E – Pielou’s index, \( n_i \) – occurrence of \( i \)-th species in sample plot, \( N \) – cumulative occurrence of species in sample plot, \( a \) – logarithmic base selected to assess entropy value (typically equal to 2 or e).

Gathering and drying of epiphytic lichens was conducted in accordance with the common procedure [4, 5]. Gathered samples were placed in paper envelopes with a field label where the following details were specified: place of gathering (point number), phorophyte, date of gathering.

![Figure 1. Outline map of the study region (Yuzhno-Sakhalinsk).](image-url)
Lichens were identified in accordance with traditional lichenological methods [4, 6]. For identification microscopes Biolam, Micromed – 2, MBS–10, chemical agents: 10% solution of KOH, saturated aqueous solution of CaCl\(_2\)O\(_2\), solution of I\(_2\) in aqueous solution of potassium iodide and alcoholic solution of paraphenylene diamine were utilized. Processing and identification of materials was performed in Phyto- and Geo-Ecology Laboratory of the Institute for Marine Geology and Geophysics of the Far East Branch of the Russian Academy of Science.

Susceptibility of lichens was defined based on confinedness to impact area allotted in view of the clustering results. To reflect a more precise level of lichen susceptibility toxiphobicity coefficient Q (or species association) determined by average number of species associated with particular species at all plots within the study regions was calculated and assigned to each species [7]. The larger the value of Q, the more susceptible the species. The following groups of susceptibility were singled out: tolerant (T), intermediately tolerant (IT), intermediately susceptible (IS), susceptible (S).

The taxons were named in accordance with Index Fungorum, CABI Bioscience Databases. In course of the study more than 400 samples of lichen were collected. Herbarium is stored at the Institute for Marine Geology and Geophysics of the Far East Branch of the Russian Academy of Science.

The impact areas were allotted with the use of Ward’s clustering method [8] on the basis of species features and lichen biota characteristics (occurrence).

Index of atmospheric purity (I.A.P.) was calculated for each control plot by formula calculated (3), suggested by LeBlanc and DeSloover [9] for assessment of industrial facilities impact of lichen biota condition in Montreal:

\[
I.A.P. = \frac{1}{10} \sum_{i=1}^{n} Q_i \times F_i
\]

where:
\(n\) – number of species at control plot, \(Q_i\) – species toxiphobicity coefficient, \(F_i\) – index of occurrence-cover of \(i\)-th species. The resulting value was divided by 10 to get a more evident figure.

4. Findings of the Study

In the studied control plots in public gardens, parks and woodlands of Yuzhno-Sakhalinsk and the suburbs 47 species of epiphytic lichens were registered.

Identified species belong to 8 orders, 14 families and 26 genera. Most species belong to orders Teloshistales D. Hawks.et O. E. Erikss (15 species, average occurrence index 76,9 %), Lecanorales Nannf. (13 species, occurrence 15,9 %), Peltigerales Walt. (7 species, 4,5 %). Other orders are represented by smaller number of species, occurrence index for separate species does not exceed 1 %.

The predominant families by number of species include Physciaceae Zahlbr. (15 species, average occurrence index 70,7 %), Parmeliaceae Zenker (5 species, 12,5 %) and Teloshistaceae Zahlbr. (5 species, 7,7 %).

The leading genera are represented by Lecanora Ach. (5 species), Caloplaca Th. Fr. (4 species), Phaeophyscia Moberg (3 species), Physconia Poelt, (3 species).

Clustering of studied plots was performed with the results used to conduct zonation of human impact of epiphytic lichens by occurrence values and species distribution characteristics at subject areas (Figure 2).

By value of Euclidean distance 3 large groups can be singled out. Group 1 includes area in vicinity of dense traffic network – public gardens and urban courtyards. Group 2 includes plots located in the municipal park and the territory of the Institute for Marine Geology and Geophysics of the Far East Branch of the Russian Academy of Science at 38-225 m distance from public roads. Group 3 includes the most remote from public roads plots with rich epiphytic lichen cover. Due to specified characteristics of the plot said groups were named zones of high exposure (urban), moderate exposure (park) and low exposure (woodlands) respectively.
The list of lichen species with indication of occurrence index, distribution of observed lichens within susceptibility groups is presented in Table 1. Lichen species observed only once were not included in any susceptibility group.

**Table 1.** The list of lichens observed in the study region with indication of susceptibility group and relative toxiphobicity coefficient (Q) for each species

| Lichens species | Q | Susceptibility group | occurrence index |
|-----------------|---|----------------------|------------------|
| Anaptychia isidiata Tomin. | 21,25 | IS | 2,3 |
| Arthonia sp. | 30 | — | 0,7 |
| Bacidia sachalinensis J. Gerasimova, A. Ezhkin & A. Beck | 25,5 | S | 2,5 |
| Buellia disciformis (Fr.) Mudd. | 23,5 | IS | 1,5 |
| Buellia erubescens Arnold. | 17 | IS | 0,4 |
| Buellia sp. | 19 | IT | 4,4 |
| Caloplaca cerina (Ehrh. ex Hedwig) Th. Fr. | 17 | IS | 0,1 |
| Caloplaca flavorebutescens (Huds.) J. R. Laundon | 19 | IS | 12,3 |
| Caloplaca gordejevi (Tomin) Oxner | 15,4 | IT | 4,9 |
| Caloplaca tarani S.Y. Kondr., S.I. Tchabanenko, I. Galana & L. Yakovcenko | 21,33 | S | 1,7 |
| Candelaria concolor (Dicks.) Stein. | 8,46 | IT | 5,7 |
| Ceratula cf. olivetorum (Nyl.) W.L.Culb. & C. F. Culb. | 21 | S | 0,3 |
| Collema furfuraceum Du Rietz | 19 | S | 19,3 |
| Collema subflacodium Degel. | 10 | S | 0,4 |
| Eopyrenula intermedia Coppins | 30 | — | 4,1 |
| Graphis rikazensis (Vain.) M. Nakan. | 30 | S | 0,7 |
| Heteroderma speciosa (Wulfen) Trevis. | 21,25 | IS | 2,1 |
| Lecanora allophana Nyl. | 17 | IS | 0,5 |
| Lecanora pachyheila Hue | 15 | IS | 5,8 |
| Lecanora sp. | 18,33 | — | 5,5 |
| Lecanora sp. 1 | 21 | — | 2,2 |
| Lecanora sp. 2 | 21 | — | 1,0 |
| Lepraria incana (L.) Ach. | 17 | IS | 0,4 |
| Leptogium burnetiae Dodge. | 21,33 | S | 1,9 |
| Leptogium cyanescens (Rabenh.) Körb | 21,25 | S | 4,3 |
| Lobaria kazawaensis Ashahina | 30 | S | 0,1 |
| Lobaria pulmonaria (L.) Hoffm. | 30 | S | 0,2 |
| Opegrapha atra Pers. | 21 | — | 0,4 |
| Oxneria huculica S. Y. Kondr. | 8 | IT | 0,9 |
| Parmelia fertilis Müll. Arg. | 16,5 | IT | 2,2 |
| Parmelia saxatilis (L.) Ach. | 13,14 | IT | 8,4 |
| Parmelia sulcata Taylor | 21 | IS | 2,1 |
| Peltigera sp. | 30 | — | 0,2 |
| Pertusaria amara (Ach.) Nyl. | 30 | S | 0,1 |
| Pertusaria pertusa (Weigel) Tuck. | 30 | S | 0,1 |
| Pertusaria sp. | 21 | — | 1,2 |
| Phaeophyscia hirtuosa (Kremp.)(Kremp.) Essl. | 10,47 | IT | 51,3 |
| Phaeophyscia hispidula (Ach.) Essl. | 19 | S | 0,7 |
| Phaeophyscia rubropulchra (Degelius) Essl. | 30 | IT | 0,2 |
| Physcia alnophila (Vain.) Loht. et al. | 30 | IS | 0,7 |
| Physcia fimbriatula (Ach.) Essl. | 5 | T | — |
| Physcia melanochla (Hue) Essl. | 5,86 | T | 3,91 |
| Physconia kurokawae Kashih. | 11 | IT | 8,0 |
| Ramalina roesleri (Hochst. ex Schaer.) Hue | 15,5 | IS | 1,2 |
| Rinodina efflorescens Malme | 30 | — | 0,2 |
The species of tolerant group – *Physciella chloantha* and *P. melanchra* – were confined to Zone 1 (urban). Lichens of tolerant group were not observed in the Woodlands Zone.

Intermediately tolerant group comprises 10 species which were observed in all exposure zones with insignificant changes in exposure gradient or increase in occurrence index in the buffer zone. The most prominent representative of the intermediately tolerant group is *Phaeophyscia hirtuosa*, its occurrence index increases abruptly in the buffer zone where it becomes the dominant of lichen biota on *Populus maximowiczii*.

Species of the intermediately susceptible groups are confined to Park and Woodlands Zones. This group includes 14 species – those are mainly prevailing lichens.

Susceptible group includes 12 species; lichens of this group are observed mostly in the zone of lower human impact. Susceptible lichen usually have high occurrence index in the zone of low exposure and are never observed in Zone 1.

To assess the overall condition of the lichen cover Index of Atmospheric Purity (I.A.P.) was calculated. The values range from 8,46 in the control urban square in closest vicinity to a public road to 49,83 in one of the woodlands plots most distant from public roads (Figure 3).

![Figure 2. Tree diagram of similarities between 15 studied plots](image)

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![Figure 3. Diagram of connection between the distance to public roads and Index of Atmospheric Purity value](image)

Figure 3. Diagram of connection between the distance to public roads and Index of Atmospheric Purity value
In general the value of I.A.P. and distance from control plot to public roads are in linear dependence, where coefficient of determination ($R^2$) is 0.83.

For urban zone I.A.P. value makes up 8.46-14.64 with a relatively small number of species (3-5). In park zone I.A.P. value increases to 13.28-20.14 with 6-11 species observed in the plot. The highest values of I.A.P. are characteristic of woodlands zone – 17.34-46.2 with 8-30 registered species of lichens.

It could be assumed that the reason for decrease in biological diversity and occurrence of epiphytic lichens on the bark of *Populus maximowiczii* is atmospheric pollution caused by road transport activities.

5. Conclusions

In the study region 47 species of lichens were registered on tree trunks. Identified species belong to 8 orders, 14 families and 26 genera. The dominant families by the number of species are *Physciaceae*, *Parmeliaceae* and *Teloschistaceae*.

The analysis of species characteristics and occurrence of lichens allowed to define the areas with characteristic sets of species corresponding to the zones of different human impact levels – urban, park and woodlands.

As the human-induced impact grows the change in species diversity can be observed – the decrease of overall number of species in urban environment; the decrease in occurrence index of intermediate susceptible and susceptible species and the increase of occurrence index of tolerant species is evidenced. With than specific distribution of separate species of different susceptibility groups can be traced depending on location of the study plot.

Coefficient of determination of dependency equation of I.A.P. value from distance to public roads is 0.83, which is highly likely to evidence that the reason for decrease in biological diversity and occurrence of epiphytic lichens on the bark of *Populus maximowiczii* is atmospheric pollution caused by road transport activities.

The distribution of lichens within exposure susceptibility groups in Yuzhno-Sakhalinsk green belt shows that atmospheric pollution is localized in the city and does not spread deep into the woodlands zone.

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