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Original Article

Lichens in the Urban Environment within South-East of Western Siberia, Russia

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Abstract

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Lichen species diversity and trend of their distribution were studied in two big cities and five towns in south-east of Western Siberia. In total of 348 species from 46 families and 98 genera were found in all studied urban and suburban areas. All local checklists are characterized by high degree of the lichen species similarity between each other and smaller lists are included in bigger ones on to 64-100%. Epiphytic lichens were the largest group in all studied areas and almost half of them were occupied two and more substrates. Crustose life-form and mesophytes prevailed everywhere. Share of sensitive lichens exceeded percent of tolerant ones in big cities and was lower than tolerant ones in smaller towns. The sixteen species were the most tolerant, commonly present everywhere and have been recognized as the key species for urban lichen synusiae within south-east of Western Siberia. Five zones have been determined with IP-mapping (mapping on the base of index of air pollution tolerance) in studied areas: IP=3-5 is a "normal zone", IP=5-7 is a "moderate exposure zone", IP=7-9 is a "mixed zone", IP=9-10 is a "struggle zone", and finally – lichen-free zone. The most studied urban areas had got quite extensive lichen-free zone (up to 35% of their areas).

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Introduction

The aim of this study was to reveal lichen species richness and trend of their distribution in urban areas with harsh continental mid-latitudinal climate. The lichens were studied in two big cities and five towns on the south-east of Western Siberia. This result is preliminary one and the research should be continued in the near future. At the beginning of this study, only a few literature data were available on lichens of the Barnaul (Skachko, 2003) and Novokuznetsk cities (Baumgertner, 1998). Only 21 and 23 lichen species have been reported from these cities, respectively. Additionally, only incomplete published data were available on lichens of the Novosibirsk city (Sedelnokova,1997; Barsukov, 2001).

During 2000-2012, lichen species diversity and distribution were investigated in urban areas of the two large Siberian industrial centers: Novosibirsk and Kemerovo, as well as in five smaller towns of Novosibirsk Region: Berdsk, Ob', Iskitim, Kol'tsovo, Krasnoobsk. The main characteristics of these areas are listed in Table 1. At the same time, similar studies were performed in Kuzbass cities: Mezhdurechensk and Osinnyki (Baumgertner, 2011, 2012). Unfortunately, there are too many inaccuracies and questionable data in some publications, and therefore, these data sources could not be fully relied upon.

Studied urban areas are located in south-east of Western Siberia (Russia) within forest-steppe zone and are characterized by harsh continental climate: with long, cold winter, but short, hot summer. The dominant native vegetation in the studied areas is birch and pine forests, birch forest outliers, willow and poplar wilds in river flood plains and grass formations. All studied cities and towns are planted with trees and shrubs quite

Table 1. The main characteristics of studied urban areas*

City	Latitude and longitude	Area size, km^2	Population in 2012.	Total annual average of atmospheric discharge, tones	Emission from vehicles,%
Novosibirsk	55°02′00″N 82°55′00″E	505.62	1498421	927023**	76.0**
Iskitim	54°38′00″N 83°18′00″E	29.9	59058	12118**	53.8**
Berdsk	54°45′00″N 83°06′00″E	67.06	98809	-	-
Ob’	54°59′30″N 82°42′45″E	21.95	26137	-	-
Kol’tsovo	54°56′20″N 83°11′00″E	18.84	13033	-	-
Krasnoobsk	54°55′00″N 82°59′00″E	15.0	19775	-	-
Kemerovo	55°20′00″N 86°04′00″E	282.3	536270	46464	60.14

* Data were taken from public sources (Novosibirsk City Department, 2012; Department of ecology press, 2012; Kemerovo City Department, 2013)

**In 2011

- Data are absent in public sources

nicely, there are sections with native forests as well as artificial planting (parks, garden squares, tree-lines etc.), but there is no district without any woody plant.

Materials and Methods

The lichens were collected in 2000-2005 within Novosibirsk city and its suburb (including south part of Kudryashovsky’s pine forest) as well as Ob’, Kol’tsovo, Krasnoobsk. In 2007, the materials were collected within Berdsk, in 2008-2009 within Kemerovo and its suburb, in 2011 within Iskitim. Fifty species collected by N.V. Sedelnikova in Novosibirsk Science Center in 1966 and in 1972-1978 (Sedelnikova, 2007; Romanova & Sedelnikova, 2010) as well as 20 species published for Kudryashovsky pine forest by Barsukov (2001) were completely verified during this study, except for one species: *Cetraria islandica* (L.) Ach. that had been found by N.V. Sedelnikova in 1966 within Novosibirsk Science Center and now it could be considered as extinct. Published data from Barnaul (Skachko, 2003), Novokuznetsk (Baumgertner, 1998, 2011), Mezhdurechensk and Osinnyki (Baumgertner, 2011, 2012) were not included in the analysis.

Each urban area has been divided onto 1 km squares. All probable habitats of lichens were explored. Ten trees of each species have been selected as a model within each square. Two 20 x 20 cm plots have been based on two levels on each tree trunk: the first plot was near butt-end, and the second one was at the height of 100 cm from the butt-end. The presence of lichens and their coverage value have been registered on plot for each species including crustose. Then all lichens on the plot have been collected and identified in the Cryptogamous Plant Laboratory of the Central Siberian Botanical Garden, SB RAS (Russia, Novosibirsk) with the application of conventional procedure. Taxonomy follows Nordin *et al.* (2010) and Mycobank. The total number of studied specimens was about 5000.

Frequency of occurrence for each species was calculated as percentage of plots with its presence. Coverage value was measured both for each species and for all lichens on the plot. Sometimes it was available to collect lichens on tree butt-end or on tree branches at additional plots, but frequency of occurrence and coverage values not estimated.

All lichens found have been regimented and analyzed into three humidity groups: mesophytes (adapted to neither a particularly dry nor particularly wet environment), xerophytes (adapted to survive in an environment with extremely low humidity) and xeromesophytes (intermediate group, species adapted to survive in quite dry conditions, but not extremely).

The asymmetrical measures of similarity (measures of inclusion) on the base of the Sørensen–Dice index were applied to compare different-sized checklists according Semkin et al. (2009):

$$K(A;B)=n(A\cap B)/n(A);\ K(B;A)=n(A\cap B)/n(B)$$

where, $n(A)$ and $n(B)$ are the number of species in samples A and B, respectively, and $n(A\cap B)$ is the number of species shared by the two samples.

Environmental quality assessment has been

realized with the geobotanical approach and Index of air pollution tolerance developed by Trass (author's term is "Poleotolerance Index": Trass, 1968, 1988; Mudd & Kozlowski, 1975):

$$IP=\sum_{i=1}^{n}(a_i c_i)/C_{in}$$

where, a_i is an air pollution tolerance value (author's term is "poleotolerance value") of each species on a scale 1-10 determined by field experience, c_i is a coverage value of each species, C_{in} is a total coverage value of lichens on a plot. IP values from each plot were averaged within 1 km square and then mapped. Only epiphytic lichens have been used for IP-mapping, because this group was the most expanded.

Air pollution tolerance value (a_i) has been determined for each species following the instructions of Trass (1968): mean frequency of occurrence as well as a coverage value have been analyzed on the transect of available lichen habitats from industrial centre of city to native plant formations without obvious signs of human impact. Appropriate a_i value has been given depending on type of habitat in which this species existed and had got the maximum of its frequency of occurrence and abundance. For example, very sensitive species (a_i =1) occurred within native intact plant formations and degraded with the slightest human impact, but highly resistant species (a_i =10) could exist within the most impacted habitats (for example, close to autobahns), although their coverage value was too poor. Intermediate a_i -groups could have the same frequency of occurrence and abundance both in light and moderate impacted habitats (a_i = 5), or could have more frequency and coverage value within impacted localities than in intact ones (a_i = 7). The detailed method description has been published in Russian (Trass, 1968) and in English (Trass, 1988), as well as a table, which have been used to determine of a_i.

Results

In total of 348 species from 46 families and 98 genera were found in all studied urban and suburban areas. Lichen species richness in studied urban areas is listed in Table 2. The main lichen genera are listed in Tables 3. Usual Parmeliaceae Zenker species were occurred and even dominated in weakly urbanized areas only, but they disappeared under hard anthropogenic pressure; the most widespread were *Parmelia sulcata* Taylor, *Flavopunctelia soredica* (Nyl.) Hale, *Hypogymnia physodes* (L.) Nyl., *Evernia mesomorpha* Nyl., *Vulpicida pinastri* (Scop.) J.-E. Mattsson. Other forest species ordinary in this climate have been found very rare (as a single specimen). The most tolerant species that are commonly present everywhere are *Caloplaca cerina* (Ehrh. ex Hedw.) Th. Fr., *C. flavorubescens* (Huds.) J. R. Laundon, *C. holocarpa* (Hoffm. ex Ach.) Wade, *Candelariella xanthostigma* (Ach.) Lettau, *Lecanora populicola* (DC.) Duby, *L. pulicaris* (Pers.) Ach., *Phaeophyscia kairamoi*

Table 2. Species richness of lichens in urban areas within south-east of Western Siberia

City/town	Species richness	% of total
Novosibirsk	279	80.2
South part of Kudryashovsky pine forest	75	21.6
Iskitim	157	45.1
Berdsk	81	23.3
Ob'	18	5.2
Kol'tsovo	45	12.9
Krasnoobsk	50	14.4
Kemerovo	178	51.1
*Novokuznetsk (Baumgertner, 1998, 2011) **	*21*	-
Osinnyki (Baumgertner, 2011)	*60*	-
Mezhdurechensk (Baumgertner, 2012)	*136*	-
Barnaul (Skachko, 2003)	*23*	-

* Published data not-included in the analysis are in italics

Table 3. Main genera of lichens in urban areas within south-east of Western Siberia

Genus	Novosibirsk		Berdsk		Krasnoobsk		Kol'tsovo		Ob'		Kemerovo		Iskitim		Kudryashovsky pine forest	
	species	%	species	%	species	%	species	%	species	%	species	%	species	%	species	%
Cladonia P. Browne	36	12.9	3	3.7	2	4.0	3	6.7	-	-	12	6.7	1	0.6	15	20.0
Lecanora Ach.	20	7.2	5	6.2	5	10.0	1	2.2	3	16.7	12	6.7	14	8.9	6	8.0
Caloplaca Th. Fr.	14	5.0	7	8.6	5	10.0	4	8.9	3	16.7	11	6.2	15	9.6	2	2.7
Peltigera Willd.	12	4.3	-	-	-	-	-	-	-	-	1	0.6	-		-	-
Bacidia De Not.	10	3.6	2	2.5	-	-	-	-	-	-	2	1.1	1	0.6	-	-
Lecania A. Massal.	10	3.6	5	6.2	4	8.0	3	6.7	1	5.6	6	3.4	6	3.8	1	1.3
Physcia (Schreb.) Michx.	9	3.2	5	6.2	5	10.0	5	11.1	2	11.1	9	5.1	9	5.7	3	4.0
Rinodina (Ach.) Gray	8	2.9	4	4.9	2	4.0	2	4.4	1	5.6	8	4.5	7	4.5	2	2.7
Arthonia Ach.	7	2.5	2	2.5	-	-	-	-	-		2	1.1	6	3.8	-	-
Buellia De Not.	7	2.5	2	2.5	1	2.0	-	-	1	5.6	3	1.7	2	1.3	2	2.7
Chaenotheca (Th. Fr.) Th. Fr.	6	2.2	2	2.5	-	-	-	-	-	-	4	2.2	-		2	2.7
Phaeophyscia Moberg	6	2.2	5	6.2	5	10.0	4	8.9	1	5.6	8	4.5	7	4.5	2	2.7
Xanthoria (Fr.) Th. Fr.	6	2.2	2	2.5	1	2.0	1	2.2	1	5.6	4	2.2	5	3.2	1	1.3
Calicium Pers.	5	1.8	-	-	-	-	-	-	-	-	-		-		-	-
Opegrapha Humb.	5	1.8	1	1.2	-	-	-	-	-	-	3	1.7	3	1.9	1	1.3
Biatora Ach.	4	1.4	-	-	-	-	-	-	-	-	4	2.2	4	2.5	-	-
Candelariella Müll. Arg.	4	1.4	3	3.7	2	4.0	2	4.4	2	11.1	4	2.2	4	2.5	4	5.3
Cliostomum Fr.	4	1.4	-	-	-	-	-	-	-	-	2	1.1	1	0.6	-	-
Lecidea Ach.	4	1.4	1	1.2	-	-	-	-	-	-	2	1.1	-		1	1.3
Melanohalea O. Blanco, A. Crespo, Divakar, Essl., D. Hawksw. et Lumbsch	4	1.4	2	2.5	2	4.0	1	2.2	-	-	4	2.2	2	1.3	3	4.0
Micarea Fr.	4	1.4	-	-	-	-	-	-	-	-	-		-		2	2.7
Physconia Poelt	4	1.4	4	4.9	3	6.0	3	6.7	1	5.6	4	2.2	5	3.2	1	1.3
Verrucaria Scop.	4	1.4	2	2.5	-	-	-	-	-	-	5	2.8	4	2.5	-	-
Acarospora A. Massal.	3	1.1	-	-	-	-	-	-	-	-	3	1.7	4	2.5	1	1.3
Leptorhaphis Körb.	3	1.1	1	1.2	1	2.0	1	2.2	-	-	3	1.7	3	1.9	1	1.3
Arthopyrenia A. Massal.	2	0.7	-	-	-	-	-	-	-	-	2	1.1	3	1.9	-	-
Chrysothrix Mont.	2	0.7	2	2.5	1	2.0	2	4.4	-	-	2	1.1	1	0.6	2	2.7
Evernia Ach.	2	0.7	2	2.5	2	4.0	2	4.4	-	-	3	1.7	2	1.3	1	1.3
Scoliciosporum A. Massal.	2	0.7	2	2.5	2	4.0	2	4.4	1	5.6	2	1.1	1	0.6	2	2.7
Aspicilia A. Massal.	1	0.4	1	1.2	-	-	-	-	-	-	5	2.8	4	2.5	2	2.7
Physciella Essl.	1	0.4	-	-	-	-	-	-	-	-	3	1.7	2	1.3	-	-
Ramalina Ach.	1	0.4	-	-	-	-	-	-	-	-	3	1.7	3	1.9	-	-

Table 4. Measures of inclusion (%) of urban areas within south-east of Western Siberia

	Novosibirsk	Berdsk	Kol'tsovo	Krasnoobsk	Ob'	Iskitim	Kemerovo	Kudryashovsky pine forest
Novosibirsk	100	98.8	100	100	100	73.9	76.4	85.3
Berdsk	28.7	100	95.6	96.0	100	41.4	42.1	53.3
Kol'tsovo	16.1	53.1	100	82.0	83.3	24.2	24.7	41.3
Krasnoobsk	17.9	59.3	91.1	100	94.4	28.0	27.5	42.7
Ob	6.5	22.2	33.3	0.34	100	10.8	9.6	20.0
Iskitim	41.6	80.2	84.4	0.88	94.4	100	64.0	50.7
Kemerovo	48.7	92.6	97.8	0.98	94.4	72.6	100	66.7
Kudryashovsky's pine forest	22.9	49.4	68.9	0.64	83.3	24.2	28.1	100

(Vain.) Moberg, *Ph. orbicularis* (Neck.) Moberg, *Physcia dubia* (Hoffm.) Lettau, *Ph. stellaris* (L.) Nyl., *Ph. tenella* (Scop.) DC., *Physconia detersa* (Nyl.) Poelt, *Ph. grisea* (Lam.) Poelt, *Rinodina pyrina* (Ach.) Arnold, *Xanthoria candelaria* (L.) Th. Fr. and *X. fallax* (Hepp) Arnold. These are recognized as the key species for urban lichen synusiae within south-east of Western Siberia.

Table 4 contains measures of inclusion between lichen checklists of studied cities and towns. All local checklists are characterized by high degree of similarity between each other and smaller lists are included in bigger ones on to 64-100 %.

Crustose lichens prevailed in all studied urban areas (Fig.1); their percentage was 48-68%. The share of foliose lichens was 22-46%, and proportion of fruticose lichens was less than 15%. Also mesophytes was the biggest group of lichens on all occasions (Fig.2), their percentage was 69-90%. The share of xerophytes was 0-9%, and percentage of intermediate group (xeromesophytes) was 5-22%.

Habitats and substrates were numerous and varied within urban environment, but lichens in studied areas preferred to live on tree-bark. Epiphytes were the largest group of lichens (Table 5) and almost half of them could occupy two and more substrates. Lichens on the natural stones have been found in native habitats only, mainly on rocky riversides (Inya river in Novosibirsk, Tom' river in Kemerovo, Shipunikha river in Iskitim), but not within industrial and residential districts, where natural lime stone and marble were available as building material or design elements. Lichens on native stones were also collected on old piles of marble and limestone near open-cut mining within and around of Iskitim. Another habitat of epilithic lichens was a huge boulders located on the coast of Novosibirsk water reservoir in the Berdsk city near the water edge, but not immersed. Lichens

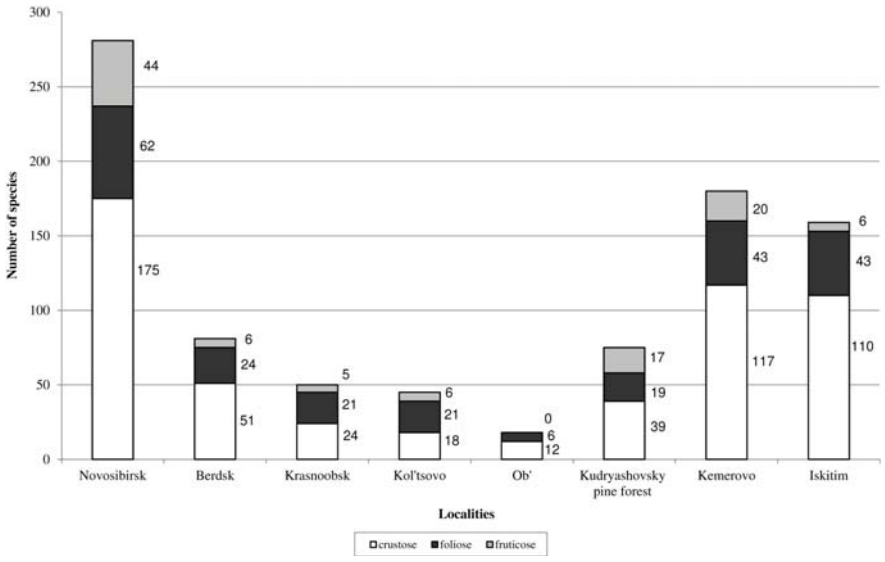

Fig. 1. Life-forms of lichens in urban areas within southeast of Western Siberia.

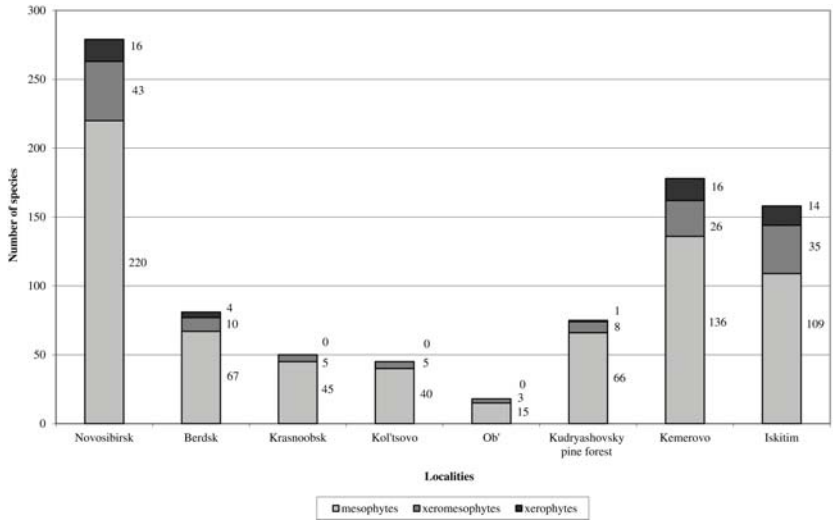

Fig. 2. Humidity groups of lichens in urban areas within southeast of Western Siberia.

Table 5. Species richness of lichens growing on different substrates in urban areas within south-east of Western Siberia

City/Town	Decidious tree bark		Coniferous tree bark		Manufactured and decaying wood		Soil		Natural stones		Artificial substrates		Two and more substrates	
	species	%	species	%	species	%	species	%	species	%	species	%	species	%
Novosibirsk	105	37.6	8	2.9	24	8.6	20	7.2	16	5.7	2	0.7	104	37.3
Berdsk	34	42.0	2	2.5	-	-	-	-	-	-	7	8.6	38	46.9
Krasnoobsk	39	78.0	1	2.0	-	-	-	-	-	-	-	-	10	20.0
Kol'tsovo	25	55.6	2	4.4	-	-	-	-	-	-	-	-	18	40.0
Ob'	15	31.2	-	-	-	-	-	-	-	-	-	-	3	16.7
Kemerovo	66	37.1	6	3.4	4	2.2	7	3.9	17	9.6	3	1.7	75	42.1
Iskitim	76	48.4	2	1.3	2	1.3	3	1.9	29	18.5	2	1.3	43	27.4
Kudryashovsky pine forest	20	26.7	6	8.0	5	6.7	3	4.0	6	8.0	-	-	35	46.7

have been presented on artificial substrates quite rarely; they have been noticed and collected on surface of old iron and concrete buildings and on synthetic fabrics under birch or pine forest canopies and under poplars or willows in river flood plains. The same artificial substrates on streets, in living districts, in parks and gardens were negligibly occupied by lichens. Lichens on the soil and fallen deadwood have been collected in suburban native pine forests only. Lichens on manufactured wood were found on palisades, on wood columns and on houses within high-density low-rise building (private housing) near streams or other water sources. Lichens did not occupy manufactured wood at arid localities within urban districts.

The highest richness of lichen species has been observed in native plant formations within and around big cities (Novosibirsk, Kemerovo) which have the maximal diversity of habitats (Table 6). Fewer, but quite a lot of lichen species have been found in parks, gardens and tree-lines (up to 67 species). Willow and poplar formations were also characterized by quite a large number of lichen species not only in natural environments, but also within urban areas.

The proportions of lichen poleotolerance values (a_i) varied in studied urban areas (Fig. 3). The share of sensitive lichens (a_i=1-3) exceeded percent of tolerant ones (a_i=8-10) in big cities. The inversed proportion was observed in smaller towns, where percentage of sensitive species was much less than tolerant ones. Neither of studied area had got 1 km square with IP <3 (Table 7). Lichen-free zone was absent in Krasnoobsk and it occupied only 10% of Iskitim. Other cities have

Table 6. Species richness of lichens in different plant formations in urban areas within south-east of Western Siberia

Plant formation	Novosibirsk	Berdsk	Krasnoobsk	Kol'tsovo	Ob'	Kudryashovsky pine forest	Kemerovo	Iskitim
Pine forest in suburb	245	-	-	-	-	75	76	53
Pine forest within city/town	101	-	-	38	-	-	75	28
Birch forest in suburb	90	-	-	-	-	-	75	81
Birch forest within city/town	81	74	50	43	-	-	47	31
Birch forest outliers in suburb	74	-	-	-	-	-	77	60
Birch forest outliers within city/town	59	46	-	-	-	-	45	45
Wilds in river flood plains in suburb	113	-	-	-	-	-	64	47
Wilds in river flood plains within city/town	35	42	-	-	-	-	71	39
Rugged river coasts with grass formations	43	-	-	-	-	-	36	51
Parks	67	35	34	-	-	-	65	46
Plantings within residential districts	54	37	29	19	18	-	66	30
Plantings along roads	22	23	21	13	-	-	25	15

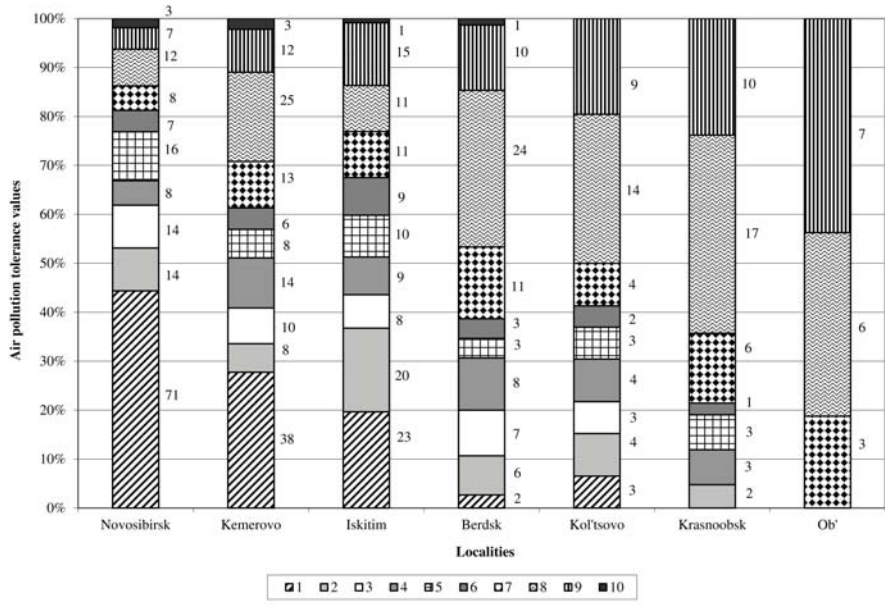

Fig. 3. Air pollution tolerance values (a_i = 1-10) of epiphytic lichens in urban areas within southeast of Western Siberia.

lichen-free zone up to 35% their areas.

Discussion

The main trend of lichen distribution over urban areas in south-east Western Siberia was the decrease of species richness and abundance (coverage value) with increasing of human impact and replacement of native plant formations by artificial planting. However taxonomic and ecological ranges of lichens in studied urban areas were quite typical for boreal plant formations. The same tendency of lichen distribution had been reported from other cities and towns of Russia, which situated in less severe climate (Byazrov, 2002; Malysheva, 2003a,b).

Novosibirsk and Kemerovo are the industrial centers. Nevertheless they have encompassed the

Table 7. Share of IP-zones in urban areas within south-east of Western Siberia

City	IP-zone, % of total city size				
	IP=3-5	IP=5-7	IP=7-9	IP=9-10	Lichen-free zone
Novosibirsk	8.5	15.3	11.6	16.5	35.0
Iskitim	-	4.2	85.8	-	10.0
Berdsk	-	24.5	43.0	-	33.0
Ob’	-	-	30.0	-	70.0
Kol’tsovo	-	60	20.0	-	17.0
Krasnoobsk	-	-	30.0	70.0	-
Kemerovo	1	20	12.7	40.0	26.3

highest species diversity with notable prevalence of sensitive species. The most likely cause of this picture is probably a wide diversity of habitats, which can be found in large urban area, including “refuges”, for example, wilds in river flood plains, big parks and fragments of native plant formations. The studied smaller towns had quite homogeneous environment without “refuges” or with native plant formations, but heavily degraded under the impact of technogenic background and human recreation. Tree-lines, small parks and other artificial plantings were the main habitats for lichens in smaller towns. This is the main cause of low diversity and prevalence of tolerant lichens in the towns.

High degrees of similarity between local checklists was duly expected, because all studied areas have been located in nearly similar climatic conditions and have analogous composition of trees and scrubs in native and artificial plant communities.

Five zones have been determined with IP-mapping in studied areas. Changes of IP-zones from “normal” to “lichen-free” within big cities were quite gradual, with all intermediate situations. Some IP-zones could be absent within small towns, and their changes were quite contrast in these areas. The most probably, IP-zones differed between each other not only by pollution with combustion gases, which harmful for lichens, but also by existence of suitable habitats in each 1 km square. IP=3-5 is a “normal zone”, which has maximal lichen species richness and sensitive species are dominants in sinusiae (Romanova, 2009). Such sections have been found within big cities only, where they have been located at the periphery of urban or in suburban areas, their border coincided with large native pine and birch forests. IP=5-7 is a “moderate exposure zone”, where both sensitive and tolerant species are dominant in lichen sinusiae. There were quite degraded under human recreation forests and forest outliers within this zone. IP=7-9 is a “mixed zone”, which are characterized by full-fledged sinusiae with tolerant lichens only. The parks, garden squares, living districts at the outskirts of the city, pieces of native plant formation within the city have been located in this zone. IP=9-10 is a “struggle zone”, where tolerant lichens exist as a small depressed thalli or as a fragment of thallus and their coverage value is extremely low. This zone was occupied the most of living districts and plantings along roads. Lichen-free zone is a land, where lichens are absent even as fragments of thalli. Industrial establishments and their neighboring lands as well as central districts (business and living squares) were located within lichen-free zone in all studied cities and towns.

Conclusion

Big cities had got the largest lichen diversity as compared smaller towns. Lichens in urban areas mostly occupied tree-bark, therefore a variety of substrates was insignificant factor for their diversity. Changes of IP-zones from “normal” to “lichen-free” were more contrast within small towns than in big cities. In the most polluted areas lichens degraded both in natural and artificial planting in the same way.

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