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Preliminary data about algae and cyanobacteria of volcanic soils on Kuril Islands

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Fifty-five species from five phyla (Cyanobacteria – 8, Chlorophyta – 29 (Chlorophyceae – 14, Trebouxiophyaceae – 11), Bacillariophyta – 19, Streptophyta – 1, Ochrophyta – 2 (Xanthophyceae – 1, Eustigmatophyceae – 1)) were revealed during the study on biodiversity of cyanobacteria and algae from terrestrial habitats of Urup, Paramushir, Iturup, and Simushir (Kuril Islands). Algal flora of Iturup Islands was the most divers with 25 species, 23 species were found on Urup, 17 on Simushir, and 14 on Paramushir Islands. Number of species per sample decreased from Urup (3.6) to Simushir (2.1), Paramushir (2.0) and Iturup (1.9). Five species, cf. *Mychonastes homosphaera*, *Chlorella vulgaris*, *Dictyococcus varians*, *Bracteacoccus minor*, and *Desmodesmus abundans* were encountered on each of the Island. In the same time species composition of cyanobacteria and algae on each Island was specific and reflected ecological peculiarities of the habitats. The most notable feature of algal and cyanobacterial flora of studied Islands was prevalence of cosmopolitan species tolerant to toxic volcanic substrates. Besides, this territory was characterized by high diversity of amphibian diatom algae. For understanding biodiversity of terrestrial algae and cyanobacteria of Kuril Islands further molecular-genetic research are necessary.

Keywords: Kuril-Kamchatka Trench, volcanic soils, eruption, resistance, spatial-ecological patterns, cf. *Mychonastes homosphaera*, *Chlorella vulgaris*, amphibian diatom algae

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Предварительные сведения о водорослях и цианобактериях вулканических почв Курильских островов

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При исследовании биоразнообразия водорослей и цианобактерий наземных местообитаний островов Уруп, Парамушир, Итуруп и Симушир (Курильские острова) было обнаружено пятьдесят пять видов, относящихся к пяти отделам: Cyanobacteria – 8, Chlorophyta – 29 (Chlorophyceae – 14, Trebouxiophyaceae – 11), Bacillariophyta – 19, Streptophyta – 1, Ochrophyta – 2 (Xanthophyceae – 1, Eustigmatophyceae – 1). Альгофлора Итурупа была наиболее разнообразной и насчитывала 25 видов, 23 вида было обнаружено на Урупе, 17 видов – на Симушире, и 14 видов – на Парамушире. Число видов в пробе уменьшалось в ряду Уруп (3,6) – Симушир (2,1) – Парамушир (2,0) – Итуруп (1,9). Пять видов – cf. *Mychonastes homosphaera, Chlorella vulgaris, Dictyococcus varians, Bracteacoccus minor, Desmodesmus abundans* – встречались на всех островах. В то же время, альгофлора каждого острова отличалась своеобразием и отражала экологические особенности местобитания. Характерной чертой альгофлоры исследованных островов было преобладание видов-космополитов, устойчивых к токсичному вулканическому субстрату. Кроме того, обнаружено большое разнообразие амфибиальных видов диатомовых водорослей. Для оценки биоразнообразия наземных водорослей и цианобактерий Курильских островов необходимы дальнейшие молекулярно-генетические исследования.

Ключевые слова: Курило-Камчатский жёлоб, вулканические почвы, извержение, устойчивость, пространственно-экологическая структура, cf. *Mychonastes homosphaera*, *Chlorella vulgaris*, амфибиальные диатомовые водоросли.

Introduction

Volcanic activity greatly affects the terrestrial ecosystems by introducing various chemical elements with volcanic emissions, altering the temperature regime, transforming existing, creating new landscapes and forms of life [1, 2]. Algae and cyanobacteria are the first organisms, settling on the lifeless substrates and initialing the succession [3–7]. Kuril Islands belong to Kuril-Kamchatka Trench (Kuril-Kamchatka volcanic belt, Kuril-Kamchatka volcanic arc) – one of the Earth's most seismically active regions. Morphogenetic types of relief of Kuril archipelago were formed under influence of the complex interactions of modern tectonic processes and volcanic activity, lithologo-stratigraphic complexes, climate and ocean fluctuations during the Quaternary period [8]. The Islands have a maritime monsoon climate that is greatly affected by air circulation and temperature regime of the Sea of Okhotsk. During the winter Kurils are under the influence of Siberian anticyclone that causes severe windy weather. In summer the Islands are influenced by oceanic air masses characterized by high temperature and humidity. A unique combination of geographical position, features of geology, relief and climate pose peculiarities of Kuril Islands flora.

Natural conditions of the Kuril Islands are not uniform. Northern Kurils belong to oceanic sector of the northern boreal subzone. This territory is characterized by a unique type of vegetation, alder bushes [9]. Central Kurils are the most severe, inaccessible and the least studied part of the archipelago [9]. Due to the extreme environmental conditions most Islands here have no forest vegetation. Southern Kurils have milder close to subtropical climate, rich floras and luxuriant vegetation.

Biological diversity of Kuril Islands in general and some groups of organisms in particular is poorly studied. Very limited data on the terrestrial algal flora of this region do not reflect the real biodiversity there [10]. In this studies algal flora of Kynashir Island near Tyatya, Golovina and Mendeleyeva volcanos were discussed. The aim of our study was investigation of biodiversity of terrestrial algae and cyanobacteria of Urup, Paramushir Iturup and Simushir Islands.

Material and methods

Thirty four soil samples were collected in 2012–2015 on Urup (7 samples) and Simushir (8 samples) islands (Central Kurils), Paramushir island (7 samples; Northern Kurils) and Iturup (12 samples; Southern Kurils).

On Urup samples were taken from the sea terrace with maritime vegetation and Mt. Rudakova slope under the canopy [11]. The soil cover at the sampling site could be characterized as volcanic soddy-humus mid-deep soil, stratified-arenaceous texture sod soil, volcanic alluvial soil, and volcanic alluvial turf soils. The vegetation included *Rosa rugosa* Thunb., *Filipendula camtschatica* (Pall.) Maxim., *Sasa kurilensis* (Rupr.) Makino et Shibata , *Cacalia robusta* Tolm., *Trollius riederianus* Fisch. et Mey, *Artemisia montana* (Nakai) Pamp., *Artemisia un-*

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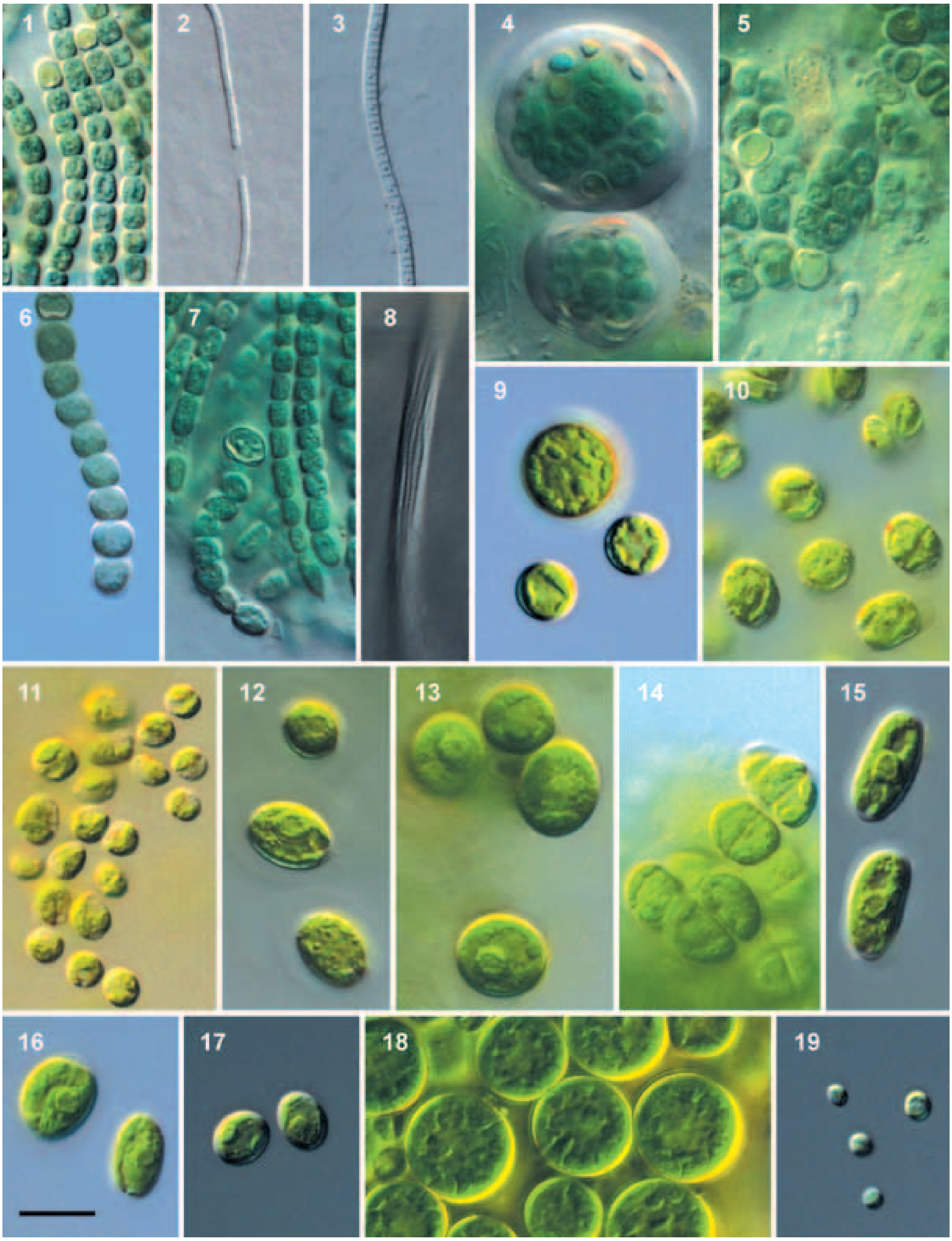

Fig. I. Terrestrial cyanobacteria and green algae of Urup, Paramushir, Iturup and Simushir Islands
1 – *Cylindrospermum* sp.; 2 – *Leptolyngbya voronichiniana*; 3 – *Leptolyngbya* cf. *valderiana*; 4 – *Nostoc minutum*; 5 – *Nostoc punctiforme*; 6 – *Nostoc* sp.1; 7 – *Nostoc* sp.2; 8 – cf.*Trichocoleus hospitus*; 9 – *Bracteacoccus minor*; 10 – *Chlamydomonas* sp.1; 11 – *Chlamydomonas* sp.2; 12 – *Chlamydomonas* sp.3; 13 – *Chlorococcum* sp.1; 14 – *Chlorosarcina brevispinosa*; 15 – *Cystomonas* sp.1; 16 – *Cystomonas* sp.2; 17 – *Desmodesmus abundans*; 18 – *Dictyococcus varians*; 19 – cf. *Mychonastes homosphaera*. Scale bar – 10 μm.

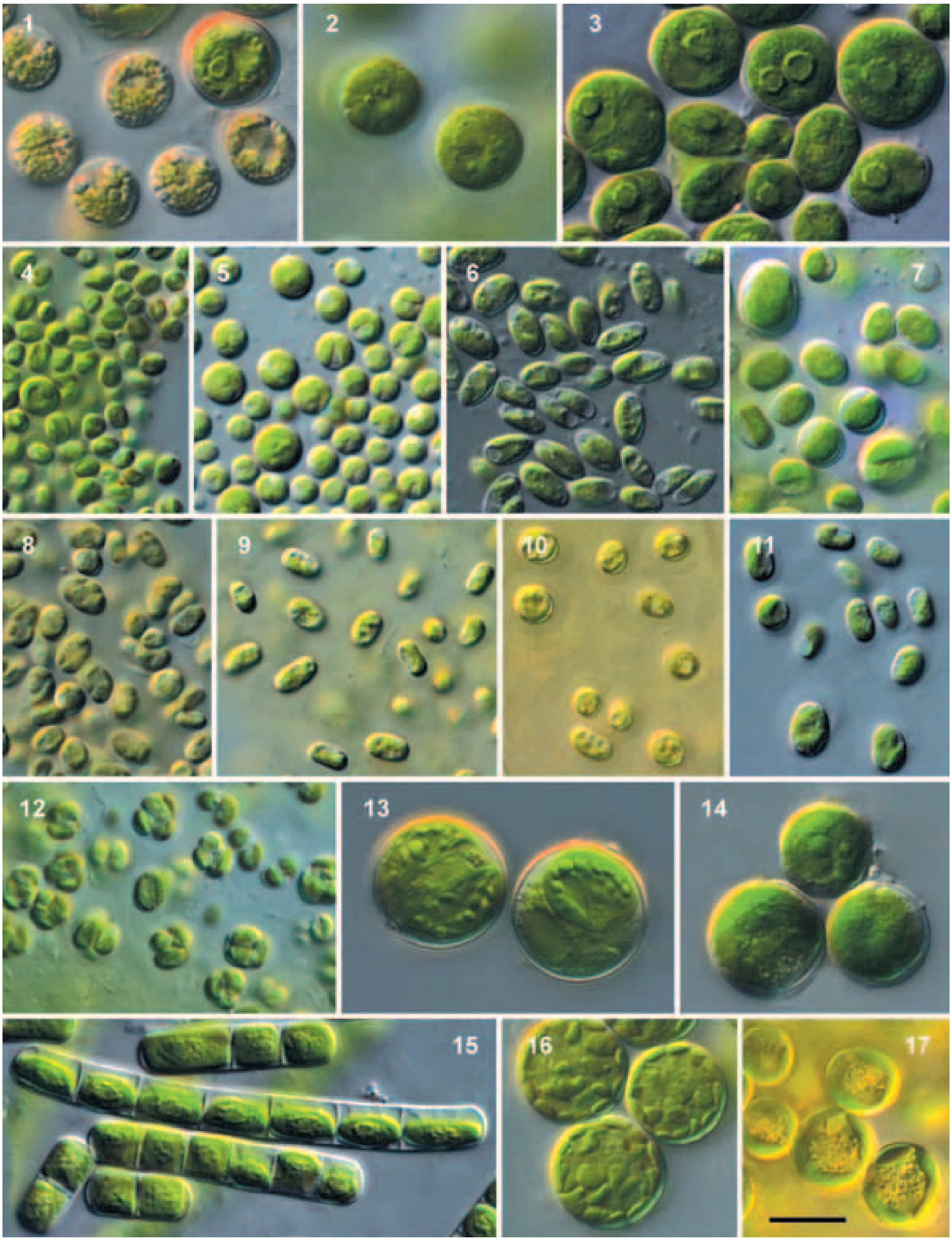

Fig. II. Terrestrial green, streptophyte and ochrophyte algae of Urup, Paramushir, Iturup and Simushir Islands
1 – *Neospongiococcum* sp.; 2 – *Palmellopsis* sp.; 3 – *Spongiococcum aplanosporum*; 4 – *Chlorella vulgaris*; 5 – *Chlorella* sp.; 6 – *Coccomyxa* sp.; 7 – *Diplosphaera chodatii*; 8 – *Neocystis* sp.1; 9 – *Neocystis* sp.2; 10 – *Neocystis* sp.3; 11 – *Neocystis* sp.4; 12 – *Neocystis* sp.5; 13 – *Lobosphaera incisa*; 14 – *Parietochloris* sp.; 15 – *Klebsormidium flaccidum*; 16 – *Botrydiopsis* cf. *arhiza*; 17 – *Eustigmatos magnus*. Scale bar – 10 µm.

alaskensis Rydb., *Artemisia tilesii* Ledeb., *Heracleum lanatum* Michx., *Calamagrostis langsdorffii* (Link) Trin., *Thalictrum minus* L., *Leymus mollis* (Trin.) Hara, *Sasa kurilensis* (Rupr.) Makino & Shibat, family Fabaceae, *Artemisia* sp., *Carex* sp. and *Calamagrostis* sp.

On Paramushir Island the samples were collected at the south-western part of the island, Krasheninnikova bay, at the foothills of Fuss Peak. Soils were of volcanic petrozem, the vegetation was composed by mosses, family Fabaceae and *Carex* sp.

On Iturup Island the samples were taken at the coasts of Dobrinia and Konservnaja bays (Chirip peninsula). In Dobrinia bay soils were volcanic lithozem and raw-organic volcanic petrozem, the vegetation was composed of *Rosa* sp. and grasses. In Konservnaja bay the soil was burozem soddy-humus and volcanic lithozem, *Alnus fruticosa* Pall. s. l., *Petasites japonicus* (Sieb.et Zucc.) Maxim., *Saxifraga* sp. and *Carex* sp.

On Simushir samples were collected from the Brouton Bay at the eastern central and western parts. At the eastern part (Vostochnaja Kleshnia Peninsula) the samples were taken from volcanic ocherous humic soil, *Filipendula camtschatica*, coastal vegetation and sedges were grown. In the center of the Brouton Bay the samples were taken from volcanic ocherous raw-organic soil, in wooded meadow dominated by *Betula* sp. and *Alnus fruticosa* Pall. s. l., *Sorbus* sp., *Salix udensis* Sekka, *Sasa kurilensis* (Rupr.) Makino et Shibata, *Calamagrostis langsdorffii* (Link) Trin., *Geranium erianthum* DC., *Maianthemum dilatatum* (Wood) A. Nelson & J.F. Macbr., *Filipendula camtschatica* (Pall.) Maxim. Samples also were taken from volcanic petrozem in *Betula ermanii* Cham. stand.

Soil samples were collected from 0–5 cm depth according to standard methods of soil phycology [12]. The samples were placed into sterile paper bags and air-dried.

In initial stages of algae and cyanobacteria cultivation Bold Basal Medium (BBM) was used [13]. Unialgal strains were isolated by the modified dilution method: 1 gram dried soil was added to 100 mL of BBM medium and grinded for 30 min by a pestle. Afterwards a few drops of the suspension were added to a Petri dish with 1.5% agar with MMB medium and distributed by the glass spatula. Initially the dishes were cultivated under 12:12 light:dark cycle at 20 °C with a photon fluence rate of 31–45 mmol · m^{-2} · s^{-1} for two weeks then at 10 °C for two months.

Algae colonies appearing in Petri dishes after 2 to 8 weeks of cultivation were transferred from the agar by Pasteur pipettes and grown on BBM agar slants, cyanobacterial colonies were grown on Z8 medium agar slants [14].

Soil cultures with fouling glasses were also used [15]. The soil was placed into the Petri dish with four sterile cover glasses on top. The sail was moisturized with distilled water to 80–100% of its full moisture capacity. The cover glasses were examined after 7–30 days of cultivation under the same conditions as described above.

Algae and cyanobacteria were identified using modern monographs and treatments [13–22]. The nomenclature used is in accordance with Algaebase [23].

Typical morphological features of filamentous taxa were filament, trichome, and cell dimensions, presence or absence of sheath, mucilage, cell color, heterocyte and akinete dimensions. For green algae the cells shape, the number and chloroplast shape, presence or absence of pyrenoid and mucilage were the basic features. In some cases for the purpose of correct identification the life cycles of algae were studied using methods described before [16] with original modifications. During identification of diatom algae cells shape and the numbers of striae in 10μm were analyzed. For representatives of phyla Ochrophyta the diagnostic characters were the cell shape, the number and chloroplast shape and presence or absence of pyrenoid. Besides, the data about species ecology were considered. The strains were examined under Axio Imager A2 light microscope equipped Axio Cam MRC Digital Camera in brightfield and differential interference contrast under ×1000 magnificationc. Microphotographs were taken with AxioVision 4.9 program.

Patterns of algae and cyanobacteria distribution on different islands were analyzed using elements of syntaxonomic analysis according to Braun-Blanquet approach [24]. The synoptic tables were prepared using the following consistency scale: r – 0,1–5%; + – 6–10%; I – 11–20%; II – 21–40%; III – 41–60%; IV – 61–80%; V – 81–100%.

Results and Discussion

Fifty-five species from five phyla (Cyanobacteria – 8, Chlorophyta – 29 (Chlorophyceae – 14, Trebouxiophyaceae – 11), Bacillariophyta – 19, Streptophyta – 1, Ochrophyta – 2 (Xanthophyceae – 1, Eustigmatophyceae – 1)) were revealed during the study on diversity of cyanobacteria and algae from terrestrial habitats of Urup, Paramushir, Iturup, and Simushir (Kuril Islands) (Fig. I–II, see color insert). Algal floras of Iturup Islands were the most divers with 25 species, 23 species were found on Urup, 17 on Simushir, and 14 on Paramushir Islands. Number of species per sample decreased from Urup (3.6) to Simushir (2.1), Paramushir (2.0) and Iturup (1.9) (Table).

Distribution of terrestrial algae and cyanobacteria on the islands studied is shown in Table. A number of species were encountered on all the islands studied. These are widely distributed in terrestrial ecosystems species of Chlorophyta – cf. *Mychonastes homosphaera* (19, Fig. I), *Chlorella vulgaris* (4, Fig. II), *Dictyococcus varians* (18, Fig. I), *Bracteacoccus minor* (9, Fig. I), *Desmodesmus abundans* (17, Fig. I) [25]. It should be noted, that representatives of several taxa could be characterized by *Mychonastes homosphaera* morphotype, and their precise identification is possible only with molecular tools [26].

Cosmopolitan species *Klebsormidium flaccidum* (15, Fig. II), *Pinnularia borealis* (14, Fig. III), as well as *Diplosphaera chodatii* (7, Fig. II) were typical species of the Urup Island (Table). Although the latter species is typical lichen photobiont [27, 28], it was also recorded in biological soil crusts in desert of the south-west USA [29, 30]. Occurrence of the class Chlorophyceae representatives *Chlamydomonas* sp.1 (10, Fig. I), *Cystomonas* sp.1. (15, Fig. I) was characteristic for the Urup Island algal flora. Trebouxiophycean algae *Lobosphaera incisa* earlier recorded near Baikal Lake, was found here [16].

A large number of diatom species was isolated from soil samples collected at the waterfront of Tokotan River and on the terrace above it in alluvial volcanic soil on Urup Island (Table). Almost all these species are widely distributed in aquatic habitats. These are freshwater *Amphora ovalis, Navicula cryptocephala, Nitzschia fonticola, Paraplaconeis placentula, Planothidium lanceolatum*, *Staurosira* cf. *construens* and *Geissleria* sp. [31–37]. *Amphora commutata* and *Navicula veneta* are more typical for brackish waters [38, 39], while *Navicula cryptocephala* occurs in both freshwater and marine habitats [37]. *Anorthoneis* sp. are mostly marine taxa [40]. *Placoneis* cf. *porifera*, was recorded in the paddy fields in Japan [41].

It is necessary to note, that most of the species, listed above often recorded in terrestrial ecosystems also. *Amphora ovalis, Navicula veneta, Nitzschia fonticola, Anorthoneis pediculus* (as *Cocconeis pediculus*), *Anorthoneis placentula* (as *Cocconeis placentula*), *Caloneis bacillum*, *Staurosira construens* var. *triundulata* (as *Fragilaria construens* var. *triundulata*), *Staurosira construens* var. binodis (as *Fragilaria construens* var. *binodis*) were found in terrestrial ecosystems in Europe and USA, including Surtsey island [19]. Surtrsey island was formed in 1963 after volcano eruption [3]. These algae could be attributed to amphibian algae, which live in both aquatic and terrestrial habitats [42].

Sea coasts are the most dynamic form of the coastal zone. Due to highly specific tidal processes taking place at the coastal zone, the latter should be regarded as a boundary between terrestrial and shallow constituents [43]. Distribution of diatom costal flora of Urup Island is similar to that of Mediterranean sandy beaches [44]. Typical marine diatom community is changes the structure first (splash zone), then transitional complex with a mixture of marine and terrestrial species is formed (5, 10, 15 m from the waterfront), and finally a complex of terrestrial species with a seldom occurrence of marine species is shaped (100–200 m from the waterfront).

Typical terrestrial algae *Palmellopsis sp.* (2, Fig. II), was found on Paramushir, Iturup and Simishir islands (Table 1). *Parietochloris sp.* (14, Fig. II), and *Eustigmatos magnus* (17, Fig. II), were recorded in algal flora of Paramushir and Simishir.

In soils of Paramushir Island representatives of the genus *Neocystis* (9, Fig. II), *Chlorella* (5, Fig. II), *Nostoc punctiforme* (5, Fig. I), *Spongiococcum aplanosporum* (3, Fig. II), and *Luticola mutica*, were found (Table). *Spongiococcum aplanosporum* was identified in samples from Paramushir Island only after study of the life cycle of the strains. This species is characterized by large (up to 30 μm) cells with large nucleus, ellipsoid zoospores with parietal chloroplast, central pyrenoid and anterior nucleus [16].

Leptolyngbya voronichiniana (2, Fig. I), known for its wide distribution in terrestrial ecosystems [45], was a diagnostic species for the Iturup Island. Beside that *Cylindrospermum* sp. (1, Fig. I), and *Nostoc* sp. (6, Fig. I), green algae from the genera *Chlamydomonas* (11, Fig. I), *Chlorococcum* (13, Fig. I), *Cystomonas* sp. 2 (16, Fig. I), *Neocystis* sp.4, *Neocystis* sp. 5 (11, 12, Fig. II), yellow-green algae *Botrydiopsis* cf. *arhiza* (12, Fig. II), were found here (Table). Diatoms were represented by the ubiquist aquatic species *Caloneis bacillum*, as well as *Nitzschia palea*, and *Pinnularia microstauron*, which could be found in freshwater and terrestrial ecosystems [19, 37].

Table

Spatial-ecological patterns of terrestrial algae and cyanobacteria at the Urup, Paramushir, Iturup and Simushir Islands (by [24])

Island / Taxon	Urup	Paramushir	Iturup	Simushir
Number of species	25	14	23	17
Number of samples	7	7	12	8
Number of species per sample	3,6	2,0	1,9	2,1
cf. *Mychonastes homosphaera* Skuja	IV	IV	IV	IV
Chlorella vulgaris Beijerinck	I	I	II	III
Dictyococcus varians Gerneck	II	I	I	I
Bracteacoccus minor (Schmidle ex Chodat) Petrová	II	I	+	II
Desmodesmus abundans (Kirchner) E.H.Hegewald	I	I	+	II
Klebsormidium flaccidum (Kützing) P.C.Silva, K.R.Mattox & W.H.Blackwell	III			
Diplosphaera chodatii Bialosukniá	II			
Navicula cryptocephala Ehrenberg	II			
Pinnularia borealis Ehrenberg	II		I	
Chlamydomonas sp.1	I			
Cystomonas sp.1	I			
Lobosphaera incisa (Reisigl) Karsten, Friedl, Schumannn, Hoyer et Lembcke	I			
Amphora commutata Grunow in Van Heurck	I			
Amphora ovalis (Kützing) Kützing	I			
Anorthoneis sp.	I			
Geissleria sp.	I			
Navicula veneta Kützing	I			
Nitzschia fonticola (Grunow) Grunow in Van Heurck	I			
Paraplaconeis placentula (Ehrenberg) M.S.Kulikovskiy & Lange-Bertalot	I			
Placoneis cf. *porifera* (Hustedt) T.Ohtsuka & Y.Fujita	I			
Planothidium lanceolatun (Brébisson ex Kützing) Lange-Bertalot	I			
Staurosira cf. *construens* Ehrenberg	I			
Palmellopsis sp.		I	I	II
Parietochloris sp.		I		II
Eustigmatos magnus (J.B.Peretsen) Hibberd		II		+
Neocystis sp.2		II		

Taxon \ Island	Urup	Paramushir	Iturup	Simushir
Chlorella sp.1		I		
Neocystis sp.1		I		
Nostoc punctiforme Kützing (Hariot)		I		
Spongiococcum aplanosporum (Arce & Bold) Shin Watanabe & L.A.Lewis		I		
Luticola mutica (Kützing) D.G.Mann in Round, R.M.Crawford & D.G.Mann		I		
Leptolyngbya voronichiniana Anagnostidis & Komárek			III	
Chlorosarcina brevispinosa S.Chantanachat & Bold			I	
Cylindrospermum sp.			+	
Nostoc sp.1			+	
Chlamydomonas sp.2			+	
Chlorococcum sp.1			+	
Cystomonas sp.2			+	
Neocystis sp.3			+	
Neocystis sp.4			+	
Caloneis bacillum (Grunow) Cleve			+	
Nitzschia palea (Kützing) W.Smith			+	
Pinnularia microstauron (Ehrenberg) Cleve			+	
Botrydiopsis cf. *arhiza* Borzì			+	
cf.*Trichocoleus hospitus* (Hansgirg ex Gomont) Anagnostidis			II	I
Nostoc minutum Desmazières ex Bornet & Flahault			+	I
Coccomyxa sp.				II
Neospongiococcum sp.				II
Leptolyngbya cf. *valderiana* (Gomont) Anagnostidis & Komarek				I
Nostoc sp.2				I
Chlamydomonas sp.3				I
Neocystis sp.5				I
Hantzschia amphioxys (Ehrenberg) Grunow in Cleve & Grunow	I		+	
Humidophila contenta (Grunow) Lowe, Kociolek, J.R.Johansen, Van de Vijver, Lange-Bertalot & Kopalová	I			I
Pinnularia subcapitata W.Gregory	I			I

Note: The synoptic tables were prepared using the following consistency scale: r – 0,1–5%; + – 6–10%; I – 11–20%; II – 21–40%; III – 41–60%; IV – 61–80%; V – 81–100%. Groups of species characteristic for the studied territories are highlighted in gray.

Cyanobacteria cf. *Trichocoleus hospitus* (8, Fig. I), and *Nostoc minutum* (4, Fig. I), characterized by nearly cosmopolitan distribution in terrestrial ecosystems [22, 45], was found on Iturup and Simushir Islands (Table).

Representatives of the genera *Coccomyxa* (6, Fig. II), and *Neospongiococcum* (1, Fig. II), were the most frequently accounted on the latter island (Table). *Leptolyngbya* cf. *valderiana* (3, Fig. I), *Chlamydomonas* sp. 3. (12, Fig. I), and *Neocystis* sp.5 (12, Fig. II), were also revealed on Simushir Island.

Ubiquitous diatoms *Hantzschia amphioxys*, *Humidophila contenta*, and *Pinnularia subcapitata* were also recorded in studied (Table). *Humidophila* members earlier have been recorded from volcanic zones (e.g. Hawaii) [46].

It should be noted that many from the species found, e.g. *Bracteacoccus minor*, *Klebsormidium flaccidum*, *Pinnularia borealis*, members of the genera *Leptolyngbya*, *Chlorella*, *Neocystis*, *Parietochloris* have been recorded during the studies on biodiversity of terrestrial algae and cyanobacteria of Kuril-Kamchatka volcanic belt [10].

To our knowledge, we present the first information on diversity and community structure of terrestrial algae and cyanobacteria of some Kuril Islands.

Conclusion

The most notable feature of algal and cyanobacterial terrestrial communities at the Urup, Paramushir, Iturup and Simushir Islands are prevalence of cosmopolitan species tolerant to toxic volcanic substrates. Besides, studied area characterized by high diversity of amphibian diatom algae.

It is necessary to note, that this results should be considered as preliminary. For understanding biodiversity of terrestrial algae and cyanobacteria of Kuril Islands further molecular-genetic research are necessary.

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Fig.3. Terrestrial diatom algae of Urup, Paramushir, Iturup and Simushir Islands
3 – Amphora commutata; 2 – Amphora ovalis; 3 – Anorthoneis sp.; 4 – Staurosira cf. construens; 5 – Hantzschia amphioxys; 6 – Humidophila contenta; 7 – Geissleria sp.; 8 – Luticola mutica; 9 – Navicula cryptocephala; 10 – Navicula veneta; 11 – Nitzschia fonticola; 12 – Nitzschia palea; 13 – Paraplaconeis placentula; 14 – Pinnularia borealis; 15 – Pinnularia subcapitata; 16 – Placoneis cf. porifera; 17 – Planothidium lanceolatun. Scale bar – 10 µm.