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The lichen family Teloschistaceae in the Altai-Sayan region (Central Asia)

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Abstract

Within the Altai-Sayan region, we identified 103 species of Teloschistaceae from 1193 field records supported by herbarium vouchers. The recorded species belong to the subfamilies *Xanthorioideae* (46 species in 14 genera) and *Caloplacoideae* (57 species in 17 genera); *Teloschistoideae* is absent. We divided the 194 surveyed localities into four categories: arid alpine, arid non-alpine, humid alpine, humid non-alpine. Each category has a specific lichen composition and a typical combination of traits. Humid non-alpine localities are mostly inhabited by broadly distributed boreal-montane species; humid alpine sites by arctic-alpine lichens; arid non-alpine habitats are preferred by xerophilous Eurasian species and arid alpine sites by xerophilous Central Asian species with (presumably) large geographic ranges in dry continental Asia. Some arid alpine species have a thick crustose thallus with a very thick medulla and cortex; this morphological trait is confined to the Central Asian group of lichens and is absent from other climatic regions, such as arctic, boreal or oceanic Eurasia. We compared species diversity in the Altai-Sayan region with the Alps. Both regions differ in species and generic composition and the richness is higher in the latter.

Taxonomy: *Caloplaca fluviatilis* is newly described. New combinations are *Pachypeltis insularis*, *P. pachythallina*, *P. phoenicopta* and *Variospora sororicida*. Two of Magnusson's names are newly synonymized: *Caloplaca infestans* with *Pachypeltis intrudens* and *Caloplaca kansuensis* with *C. bicolor*. In addition to 22 known genera, we define, provisionally, 9 groups of species that may merit recognition as genera. *Caloplaca epithallina* is provisionally placed in *Shackletonia*, but we do not formally publish a new combination. Lichenicolous *Pachypeltis phoenicopta* and *Variospora sororicida* are less host-specific than originally thought.

Floristics: *Caloplaca pratensis* is new to Eurasia, *Caloplaca helygeoides* (= *C. diphyodes* auct.), *C. monacensis* and *C. soralifera* are new to Asia. 12 species are new to Russia, 9 new to Siberia, 9 new to China, 2 new to Kazakhstan, and 2 new to Xinjiang. Outside the studied region *Pachypeltis phoenicopta* is new to Europe (Spain, Sierra Nevada) and we report the first reliable record of *Pachypeltis insularis* from Greece (Mt Olympus).

Notes

(1) Throughout this paper we use the words "genus" and "genera" to include genera that have been formally published as such and groups of species within Teloschistaceae that, in our opinion, probably merit recognition at generic rank. (Further discussion in the taxonomic part.)

(2) We distinguish between *Caloplaca* sensu stricto and '*Caloplaca*' sensu lato, i.e. species traditionally placed in *Caloplaca*, but which are outside *Caloplaca* in the sense of Arup *et al.* (2013). We denote them as *Caloplaca* and *'Caloplaca'* respectively (i.e. the latter is in quotes). (The Abstract, above, does not follow this convention.)

Introduction

The Altai-Sayan region is an area of Central Asia including large territories of south-western Siberia (Russia) and adjacent regions in north-western China, western Mongolia and eastern Kazakhstan. It covers an area of just over 1 milion square kilometers. The Altai-Sayan mountain region is one of the world biodiversity centres for plants and animals and is included in the "Global 200" list of virgin or little changed ecoregions in the world, where more than 90% of the planet's biodiversity is concentrated (Olson & Dinerstein 2009). It is considered to be one of the centres of biodiversity and endemism for vascular plants (Kamelin 2005, Pyak *et al.* 2008). The first data on its lichen biota were published in the 19th century (Georgi 1800, 1802, Martianov 1882, Wainio 1887, 1894, 1896, 1897–1898) and research has continued to the present (Rassadina 1938, Andreeva, 1978, 1983, 1987, Golubkova 1981, Makryi 1986; Sedelnikova 1990, 2003, Abbas *et al.* 2001, Davydov 2001, 2004, Davydov *et al.* 2007, 2012, Davydov & Printzen 2012a, b, Biazrov 2013, Davydov & Yakovchenko 2017). There are fewer studies from the Sayan Mountains than from Altai; lists were published by Sedelnikova (1996a+b, 2001).

Teloschistaceae is a species rich lichen family (Lücking *et al.* 2016), diverse in morphology and occupying various terrestrial habitats. It has not been studied critically in the region. Although the list compiled for the Altai-Sayan region includes 94 species (Sedelnikova 2013), reliability of the sources is low. The region has many organic and inorganic substrates along large ecological gradients, especially in altitude and aridity/humidity, so might be expected to be rich in species of Teloschistaceae.

Our work had two goals. The first goal was to describe regional taxonomic diversity in Teloschistaceae in a form suitable for comparing lichen diversity with other world regions. The second was to look for links between occurrences of taxonomic groups or particular traits and various natural conditions in the region.

Our field observations suggested the following hypotheses: (1) Teloschistaceae has high generic and species richness in the region; (2) Dry habitats are mainly inhabited by xerophilous Central Asian species, whereas humid habitats are occupied by boreal and alpine species; (3) Species richness decreases in the gradient from arid alpine to humid non-alpine habitats; (4) Some traits and taxonomic groups are confined to, or strongly prefer specific types of habitats; (5) The composition of species and genera differs from European mountain regions. These field hypotheses are tested below.

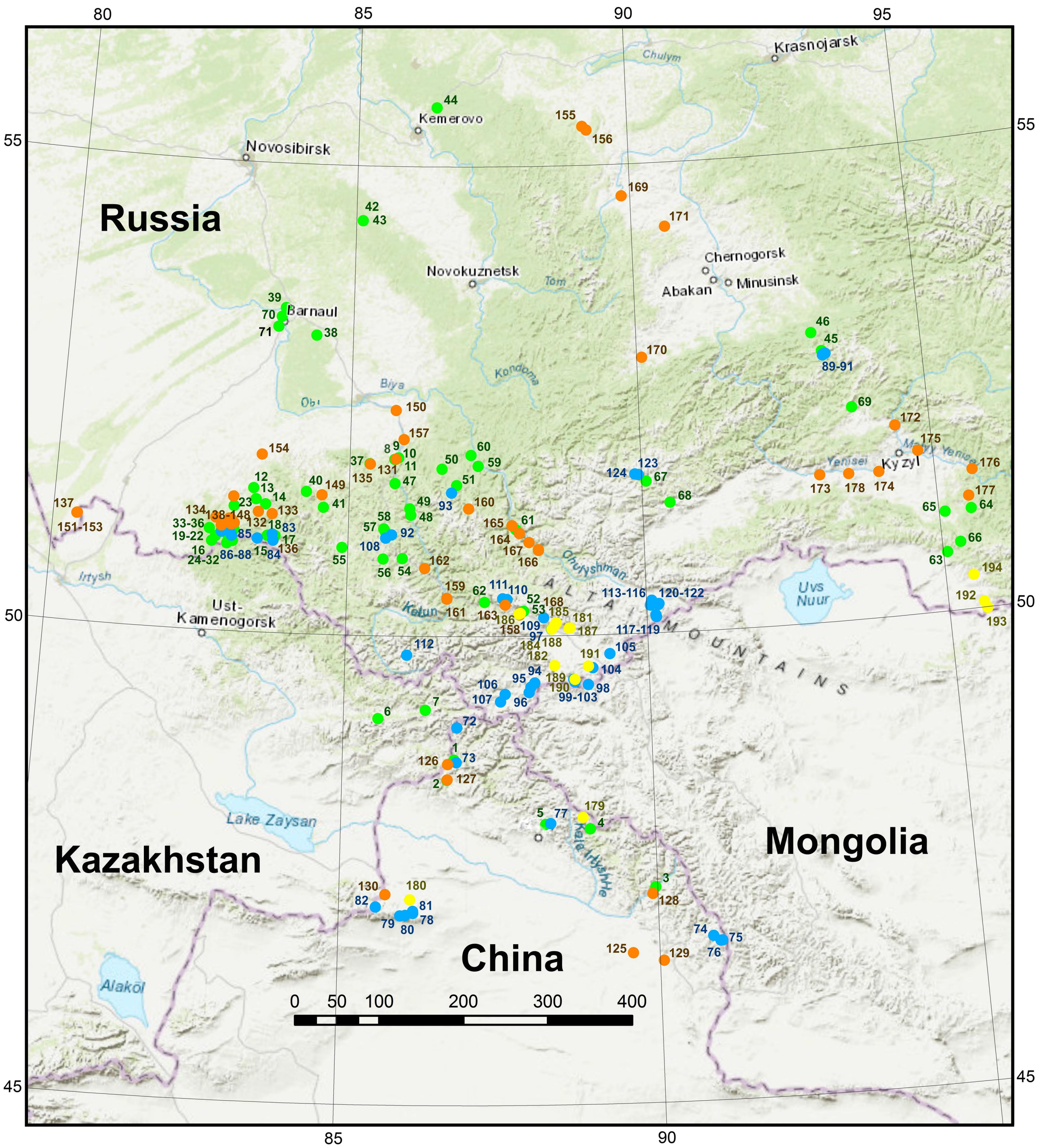

FIGURE 1. Sampling sites. Green-humid non-alpine, blue-humid alpine, orange-arid non-alpine, yellow-arid alpine. Numbers of sites correspond with Appendix 1.

Materials & methods

Territory of research, sampling and voucher deposition

The Altai-Sayan region, as defined here, refers to Altai and the Western Sayan Mountains and adjacent regions in the north (Altai Territory, Khakassia, Kemerovo Region, Krasnoyarsk Territory) and south-east (Tyva). The Eastern Sayan Mountains were not investigated.

The Altai-Sayan region is an extensive mountain region situated in central Eurasia. It contains the highest mountain range in Siberia. The basic topography is high mountain ranges with deep inter-montane depressions. The flat and gently-rolling plains below the foothills of the Altai-Sayan mountains (altitude 200–300 m) are composed of thin loessic loams over Tertiary sandy clay rocks, whereas the foothills (up to 400–500 m) are formed of dense metamorphic and intrusive Paleozoic rocks. The mid-slopes and tops of the high mountains are mainly Paleozoic sandstones, slates and in some places limestone, with numerous granite intrusions. The mountain tops are either plateau-like or formed by sharply shaped summits. The highest summits rise above the snow line which is at 2700–2950 m altitude (Strelkov & Vdovin 1969, Pyak *et al.* 2008). The highest mountain is Mt Belukha, 4506 m. The Altai-Sayan mountains give rise to several streams and rivers, most of which eventually join the Ob' and Yenisei Rivers. The regional climate is severely continental, and the continentality increases from the West, where the mean annual temperature is more than +2°C, to the East, where it is less than –4°C. Because of the influence of the Asiatic anticyclone, the winter is long (5–9 months) and very cold. January temperatures range from –10–15°C in the foothills to –25–30°C in the basins of the east. Summer at the elevation of 1000 m is short and cool. July temperatures range from 18–20°C in the North-West to 14–16°C in the South-East. The transitions between summer and winter are sharp, particularly in the alpine belt. The western and north-eastern parts of Altai have a humid climate and annual precipitation locally exceeds 1000 mm in the northern Altai foothills. Humidity decreases sharply towards the south-east, where the arid inter-montane basins have low annual precipitation (100–200 mm) and snowless winters. The geographical position of the Altai-Sayan is responsible for the great variety of its biomes: desert, semi-desert, steppe, forest-steppe, and boreal forests predominantly with *Abies sibirica*, *Betula pendula*, *Larix sibirica*, *Picea obovata*, *Pinus sibirica, P. sylvestris* and *Populus tremula*. The large vertical relief increases this variety further: lowland shrub steppe gives way to forest-steppe, different types of taiga forest, *Betula* forests, subalpine meadows with shrubs and herbs, alpine meadows, and eventually mountain tundra (Kuminova 1960, Kamelin 1998, 2005; see also the environmental classification below). We report on 1193 specimens collected from 194 sites (Fig. 1, Appendixes 1 & 2) at altitudes 200–3500 m; 166 sites in Russia, 25 in Xinjiang in China and 3 in eastern Kazakhstan. Specimens are deposited in herbaria PRA (Vondrák), ALTB (Davydov) and in Frolov's personal herbarium. Records not supported by herbarium specimens are not included. The collections are from two excursions by Vondrák and Frolov to survey diversity of Teloschistaceae in Altai and adjacent regions in 2012 (383 collections), in Western Sayan and adjacent regions in 2013 (530 collections), and data recorded during numerous floristic field trips in 1995–2017, mostly by Davydov and Yakovchenko (280 collections).

Sequencing and phylogenetic reconstructions

Barcode ITS sequences were obtained for 129 specimens (Table 1). DNA was extracted with a CTAB-based protocol (Aras & Cansaran 2006). The ITS region (including ITS1, 5.8S and ITS2) of the nuclear ribosomal genes was amplified using the primers ITS1F *5'CTTGGTCATTTAGAGGAAGTAA* and ITS4 *5'TCCTCCGCTTATTGATATGC*. Sequences were edited in BioEdit 7.2.5 (Hall 1999) and all alignments were done by MAFFT version 7 (Katoh and Standley 2013; available online at http://mafft.cbrc.jp/alignment/server/) with the default method (FFT-NS-1, FFT-NS-2, FFT-NS-i or L-INS-i; Katoh *et al.* 2005). All analyses of DNA sequence data were done on the CIPRES Science Gateway (Miller *et al.* 2010).

Maximum likelihood (ML) analysis was performed for an ITS-based phylogenetic reconstruction of the whole Teloschistaceae dataset, i.e. our 129 new sequences together with 2516 sequences downloaded from GenBank (NCBI). Analysis was run in RAxML v8.2.10 (Stamatakis 2014) with the GTR model of nucleotide substitution with the addition of invariant sites and a gamma distribution (GTRGAMMA+I). Nodal support was evaluated using 1000 bootstrap pseudoreplicates.

To obtain a more precise tree topology, sequences of the following groups were aligned and analyzed separately: *Caloplaca* sensu stricto, *Pachypeltis*, *Rufoplaca*, *Rusavskia*, *Shackletonia*, *Variospora* and '*Caloplaca*' *anularis* group and '*Caloplaca*' *exsecuta* group. Phylogenetic reconstructions were carried out using Bayesian inference and maximum likelihood. For Bayesian analyses, gaps were coded as binary data in SeqState by simple coding (Simmons & Ochoterena 2000). Analyses were done in MrBayes 3.2.6 (Ronquist & Huelsenbeck 2003) using two independent runs with four MCMC chains; trees were sampled after every 500th generation; the analyses were stopped after 10 milion generations. The first 25% of trees were discarded as the burn-in phase, and the remaining trees were used to construct a 50% majority rule consensus tree. Maximum Likelihood (ML) analyses were run in RAxML v8.2.10 (Stamatakis 2014) with the GTRGAMMA+I model of nucleotide substitution and with the use of 1000 bootstrap pseudoreplicates. Only Bayesian tree topologies with posterior probabilities were visualised (Figs 6, 8, 9, 11, 13, 14 & 16). Branches with posterior probabilities ≥0.95 indicated by thick line. Maximum likelihood trees were not shown, but their topologies never had conflicting branching patterns with Bayesian trees.

TABLE 1. Specimens with newly generated ITS sequences.

Species	Voucher	Geography	Substrate	Co-ordinates	Altitude (m)	NCBI accession
Amundsenia approximata	Vondrák 18142	Russia, Altai	schist	51.5292, 86.7462	2030	MH155294
Athallia holocarpa	Vondrák 18072	Russia, Altai	siliceous stone	51.9314, 87.0790	425	MG954144
Athallia pyracea	Vondrák 18070	Russia, Altai	bark of *Picea obovata*	50.3656, 87.3017	1200	MG954145
Athallia pyracea	Vondrák 18039	Russia, Altai	limestone	50.3656, 87.3017	1200	MG954146
Athallia pyracea	Vondrák 18149	Russia, Altai	bark of *Populus*	51.1378, 87.8355	500	MG954147
Athallia saxifragarum	Vondrák 12714	Russia, Altai	plant debris	50.1382, 88.4935	3050	MG954141
Athallia saxifragarum	Vondrák 12712	Russia, Altai	plant debris	50.1382, 88.4935	3050	MG954142
Athallia sp.	Frolov 1599	Russia, Altai	wood of *Lonicera* sp.	50.1078, 88.4578	2000	MG954143
Bryoplaca jungermanniae	Vondrák 18055	Russia, Altai	soil bryophytes	50.3941, 87.6768	2575	MG954126
Calogaya zoroasteriorum	Frolov 1597	Russia, Altai	wood of *Lonicera* sp.	50.1078, 88.4578	2000	MG954182
Calogaya biatorina	Frolov 64	Russia, Altai	limestone	52.0952, 85.9237	250	MG954184
Calogaya ferrugineoides	Vondrák 18060	Russia, Altai	twig of *Lonicera* sp.	50.1078, 88.4578	2500	MG954179
Calogaya ferrugineoides	Vondrák 18061	Russia, Altai	twig dead shrub	50.0817, 88.7189	2050	MG954180
Calogaya ferrugineoides	Davydov 17046	Russia, Altaisky krai	branches dead shrub	51.1432, 80.4078	227	MG954206
Calogaya ferrugineoides	Davydov 17049	Russia, Altaisky krai	branches dead shrub	51.1432, 80.4078	227	MG954207
Calogaya pusilla	Vondrák 18221	Russia, Khakasia	limestone	54.3189, 90.6105	470	MG954181
Calogaya saxicola s.lat.	Davydov 17045	Russia, Altaisky krai	quartzite	51.1432, 80.4078	227	MG954208
Calogaya xanthoriella ined.	Frolov 1598	Russia, Altai	wood of *Lonicera* sp.	50.1078, 88.4578	2000	MG954183
Caloplaca' ahtii	Urbanavichene (PRA)	Russia, Stanovoe nagorie	bark of *Chosenia arbutifolia*	56.316, 116.847	500	MG954161
'Caloplaca'anularis	Vondrák 9927	Russia, Altai	limestone	50.1382, 88.4935	3000	MG954136

...continued on the next page

TABLE 1. (Continued)

Species	Voucher	Geography	Substrate	Co-ordinates	Altitude (m)	NCBI accession
'Caloplaca'anularis	Vondrák 18201	Russia, Tuva	limestone	50.0655, 95.5856	1530	MG954140
'Caloplaca'borealis	Vondrák 11073	Russia, Western Sayan	twig of *Abies sibirica*	52.8375, 93.2650	1525	MG954129
'Caloplaca'cf. bohlinii	Vondrák 18216	Russia, Tuva	limestone	50.0655, 95.5856	1530	MG954138
'Caloplaca'cf. bohlinii	Vondrák 18215	Russia, Tuva	limestone	51.5694, 93.0436	750	MG954139
'Caloplaca'congrediens	Vondrák 14036	Turkey, Gaziantep	volcanic rock	37.1036, 37.0358	950	MG954115
'Caloplaca'conversa	Vondrák 10289	Russia, Altai	volcanic rock	51.6255, 85.7790	500	MG954112
'Caloplaca'conversa	Vondrák 10265	Russia, Altai	gneiss	51.1799, 87.7729	500	MG954113
'Caloplaca'epithallina	Vondrák 9395	Russia, Orenburg region	volcanic rock	52.0455, 58.7725	280	MG954201
'Caloplaca'epithallina	Vondrák 8003	USA, California, Hot Creek	siliceous rock, lichenicolous	38.34, –119.42	2200	MH155282
'Caloplaca'epithallina	Urbanavichus (PRA)	Russia, Caucasus	soil mosses, partly on *Candelariella*	43.2811, 42.4619	3160	MH155283
'Caloplaca'epithallina	Urbanavichus (PRA)	Russia, Caucasus	soil mosses, partly on *Candelariella*	43.2811, 42.4619	3160	MH155284
'Caloplaca'exsecuta	Vondrák 11105	Russia, Western Sayan	schist	51.6910, 89.8872	2175	MG954130
'Caloplaca'exsecuta	Vondrák 11110	Russia, Western Sayan	schist	51.6910, 89.8872	2175	MG954131
'Caloplaca'exsecuta	Tonsberg 46194	Norway, Sogn og Fjordane	siliceous rock	61.7651, 6.5020	630	MG954211
'Caloplaca'exsecuta	Zhdanov sn	Russia, arctic	antler of reindeer in tundra	NA	NA	MG954223
'Caloplaca'exsecuta	Spribille 39677	USA, Alaska	siliceous rock	58.2486, –136.5707	22	MG954224
'Caloplaca'exsecuta	Vondrák 7420	Russia, Barents Sea coast	granite	NA	NA	MG954225
'Caloplaca'exsecuta	Vondrák 6201	Ukraine, Eastern Carpathians	sandstone above timber line	48.2710, 24.2036	1300	MG954226
'Caloplaca'exsecuta	Spribille 24441	USA, Alaska, Klondike GRN National Historical Park	siliceous rock	NA	NA	MG954227
Caloplaca fluviatilis	Vondrák 11104	Russia, Tuva	siliceous stone	51.6189, 90.0764	1490	MG954127
Caloplaca fluviatilis	Vondrák 18229	Russia, Tuva	siliceous stone	51.4003, 90.4448	1120	MG954128
'Caloplaca'lucifuga	Vondrák 7931	Czech Republic	bark *Quercus robur*	49.0969, 14.4644	370	MG954215

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TABLE 1. (Continued)

Species	Voucher	Geography	Substrate	Co-ordinates	Altitude (m)	NCBI accession
'Caloplaca'lucifuga	Vondrák 8431	Czech Republic	bark *Quercus*	48.9337, 15.7161	390	MG954216
'Caloplaca'lucifuga	Vondrák 8433	Czech Republic	bark *Quercus*	49.0753, 14.4522	430	MG954217
'Caloplaca'nivalis	Spribille 29306	USA, Alaska, Klondike GRN National Historical Park	mosses on siliceous rock	NA	NA	MG954222
'Caloplaca'percrocata	Davydov 12295	Russia, Altai	siliceous rock	49.8000, 86.0167	2300	MG954219
'Caloplaca'phaeothamnos	Vondrák Sel. Exs.Cal.70	Turkey, Lake Van	volcanic rock	38.9969, 43.5002	1670	MG954114
'Caloplaca'scrobiculata	Vondrák 9933	Russia, Altai	limestone	50.1382, 88.4935	3000	MG954135
'Caloplaca'sororapa	Vondrák 12695	Russia, Western Sayan	twig *Grossularia*	52.8491, 93.2809	1575	MG954132
'Caloplaca'sp.	Vondrák 18687	Russia, Tuva	wood *Larix decidua*	51.4003, 90.4448	1120	MG954157
'Caloplaca'sp.	Palice 12359	Austria, Gurktaler Alpen	mica-schist	46.8811, 13.7292	2075	MG954200
'Caloplaca'teicholyta	Vondrák 12688	Russia, Tuva	limestone	50.3589, 95.4617	1900	MG954205
'Caloplaca'tornoensis	Spribille 26816	USA, Alaska, Klondike GRN National Historical Park	mosses on siliceous boulder	NA	NA	MG954220
'Caloplaca'tornoensis	Spribille 29473	USA, Alaska, Klondike GRN National Historical Park	mosses on siliceous rock	NA	NA	MG954221
'Caloplaca'zeorina	Vondrák 9928	Russia, Altai	limestone	50.1382, 88.4935	3000	MG954137
Flavoplaca flavocitrina	Vondrák 18152	Russia, Altai	limestone	51.8285, 85.3484	550	MG954193
Flavoplaca flavocitrina	Vondrák 18157	Russia, Altai	limestone	52.0952, 85.9237	250	MG954194
Flavoplaca oasis	Vondrák 18162	Russia, Altai	limestone	51.8323, 85.3426	500	MG954195
Flavoplaca oasis	Vondrák 18222	Russia, Khakasia	limestone	54.6633, 89.8430	410	MG954196
Flavoplaca oasis	Vondrák 18220	Russia, Tuva	limestone	50.3589, 95.4617	1800	MG954197
Flavoplaca oasis	Vondrák 18066	Russia, Altai	siliceous rock	51.3583, 86.0358	710	MG954198
Flavoplaca oasis	Vondrák 18217	Russia, Tuva	limestone	50.3589, 95.4617	1900	MG954199

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TABLE 1. (Continued)

Species	Voucher	Geography	Substrate	Co-ordinates	Altitude (m)	NCBI accession
Gyalolechia flavorubescens	Vondrák 18063	Russia, Altai	bark of *Populus*	51.1378, 87.8355	500	MG954133
Gyalolechia fulgens	Vondrák 18219	Russia, Krasnoyarsk region	soil	55.4158, 89.1608	400	MG954134
Pachypeltis aff. pachythallina	Vondrák 12706	Russia, Altai	limestone lichenicolous	50.1078, 88.4578	2650	MG954163
Pachypeltis insularis	Frolov 87a (bright)	Russia, Altai	limestone	50.1382, 88.4935	2700	MG954166
Pachypeltis insularis	Frolov 87b (pale)	Russia, Altai	limestone	50.1382, 88.4935	2700	MG954167
Pachypeltis insularis	Frolov 1671	Greece, Olympus	limestone	40.0829, 22.357	2866	MG954168
Pachypeltis insularis	Vondrák 12709	Russia, Altai	limestone lichenicolous	50.1078, 88.4578	2650	MG954169
Pachypeltis intrudens	Vondrák 18059	Russia, Altai	siliceous rock lichenicolous	49.6836, 88.4514	2200	MG954164
Pachypeltis intrudens	Frolov 56	Russia, Altai	limestone	50.1382, 88.4935	2700	MG954165
Pachypeltis phoenicopta	Vondrák 18026	Russia, Altai	siliceous rock lichenicolous	50.1078, 88.4578	2500	MG954170
Pachypeltis phoenicopta	Vondrák 18027	Russia, Altai	schist lichenicolous	50.2309, 87.8821	1525	MG954171
Pachypeltis phoenicopta	Vondrák 18191	Spain, Sierra Nevada	siliceous rock lichenicolous	37.09724, –3.3874	2500	MG954218
Parvoplaca tiroliensis	Vondrák 10350	Russia, Altai	soil bryophytes	50.1382, 88.4935	3050	MG954162
Parvoplaca tiroliensis	Vondrák 18144	Russia, Altai	bryophytes	50.3941, 87.6768	2575	MG954202
Rufoplaca arenaria sensu lato	Vondrák 18371a	Russia, Western Sayan	mineralized wood of *Larix* log	51.4003, 90.4448	1120	MH155289
Rufoplaca arenaria sensu lato	Vondrák 18371b	Russia, Western Sayan	mineralized wood of *Larix* log	51.4003, 90.4448	1120	MH155290
Rufoplaca arenaria sensu lato	Vondrák 18693	Russia, Western Sayan	siliceous stone	51.4003, 90.4448	1120	MH155293
Rufoplaca sp. (on *Dimelaena*)	Vondrák 8527	Turkey, Lake Van	volcanic rock, lichenicolous on *Dimelaena oreina*	38.8614, 42.3388	1830	MH155285
Rufoplaca sp. (on *Dimelaena*)	Vondrák 8155	Turkey, Lake Van	volcanic rock, lichenicolous on *Dimelaena oreina*	38.9970, 43.5002	1740	MH155286
Rufoplaca sp. 1	Vondrák 18198	Russia, Tuva	granite	51.4736, 95.6353	820	MG954204
Rufoplaca sp. 1	Vondrák 9931	Russia, Altai	siliceous rock	51.2899, 86.0547	500	MH155279
Rufoplaca sp. 1	Vondrák 9917	Russia, Altai	gneiss rock	50.9133, 88.2151	1150	MH155281

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TABLE 1. (Continued)

Species	Voucher	Geography	Substrate	Co-ordinates	Altitude (m)	NCBI accession
Rufoplaca sp. 1	Vondrák 18330	Russia, Tuva	sandstone	49.9933, 95.6272	1400	MH155292
Rufoplaca sp. 2	Vondrák 18681	Russia, Western Sayan	gneiss	51.6911, 89.9458	2050	MG954203
Rufoplaca sp. 2	Vondrák 9924	Russia, Altai	gneiss rock, lichenicolous	49.4013, 88.0247	3000	MH155280
Rufoplaca sp. 2	Urbanavichus (PRA)	Russia, Caucasus	siliceous rock, lichenicolous on *Miriquidica deusta*	43.2811, 42.4619	3160	MH155287
Rufoplaca sp. 3	Davydov 17245	Russia, Altai	siliceous rock	50.9500, 82.7000	500	MG954209
Rufoplaca subpallida sensu lato	Vondrák 9929	Russia, Altai	gneiss rock	51.1407, 85.5997	1200	MH155278
Rufoplaca subpallida sensu lato	Vondrák 18691	Russia, Western Sayan	siliceous stone	52.8541, 93.3132	1700	MH155288
Rufoplaca subpallida sensu lato	Vondrák 18371c	Russia, Western Sayan	mineralized wood of *Larix* log	51.4003, 90.4448	1120	MH155291
Rusavskia dasanensis	Vondrák 18204	Russia, Western Sayan	schist	52.2603, 93.6931	1440	MG954156
Rusavskia dasanensis	Vondrák 18102	Russia, Altai	limestone	51.8285, 85.3484	550	MG954155
Rusavskia elegans (large thallus)	Vondrák 18104	Russia, Altai	siliceous stone	51.0426, 85.6358	1800	MG954148
Rusavskia elegans (small thallus)	Vondrák 18105	Russia, Altai	siliceous stone	51.0426, 85.6358	1800	MG954149
Rusavskia elegans (small thallus)	Vondrák 18212	Russia, Tuva	siliceous stone	51.6189, 90.0764	1490	MG954152
Rusavskia elegans (small thallus)	Vondrák 18211	Russia, Tuva	limestone	51.7308, 94.7508	1225	MG954153
Rusavskia elegans (small thallus)	Vondrák 18208	Russia, Tuva	sandstone	50.6286, 95.0683	1400	MG954154
Rusavskia sp. 1 (Xanthoria-like)	Vondrák 18103	Russia, Altai	limestone	51.8285, 85.3484	550	MG954151
Rusavskia sp. 1 (Xanthoria-like)	Vondrák 18207	Russia, Tuva	limestone	50.0655, 95.5856	1530	MG954159
Rusavskia sp. 2 (with appressed lobes)	Vondrák 18161	Russia, Altai	schist	50.2309, 87.8821	1525	MG954150
Rusavskia sp.	Vondrák 18225	Russia, Khakasia	siliceous rock	54.6633, 89.8430	410	MG954158
Squamulea sp.	Vondrák 18682	Russia, Tuva	sandstone	51.5500, 94.0542	660	MG954160
Variospora dolomiticola	Vondrák 18202	Russia, Tuva	limestone	50.3589, 95.4617	1700	MG954124
Variospora dolomiticola	Vondrák 18218	Russia, Tuva	limestone	50.0655, 95.5856	1530	MG954125

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TABLE 1. (Continued)

Species	Voucher	Geography	Substrate	Co-ordinates	Altitude (m)	NCBI accession
Variospora sororicida	Vondrák 18069	Russia, Altai	limestone lichenicolous	50.2372, 87.8722	1640	MG954116
Variospora sororicida	Vondrák 12686	Russia, Tuva	limestone lichenicolous	50.3589, 95.4617	1900	MG954117
Variospora sororicida	Vondrák 18223	Russia, Tuva	limestone	51.7308, 94.7508	1230	MG954118
Variospora sororicida	Vondrák 18203	Russia, Tuva	limestone lichenicolous	50.0655, 95.5856	1530	MG954119
Variospora sororicida	Vondrák 18679	Russia, Tuva	limestone lichenicolous	50.0655, 95.5856	1530	MG954120
Variospora sororicida	Vondrák 18692	Russia, Tuva	limestone lichenicolous	50.0655, 95.5856	1500	MG954121
Variospora sororicida	Vondrák 18685	Russia, Tuva	limestone	51.4736, 95.6353	820	MG954122
Variospora sororicida	Vondrák 10450	Russia, Altai	limestone lichenicolous	50.3996, 86.6756	850	MG954123
Xanthocarpia crenulatella	Vondrák 18197	Russia, Tuva	concrete	51.1992, 95.5258	840	MG954192
Xanthocarpia ferrarii	Vondrák 18195	Russia, Tuva	schist	52.0239, 94.4052	730	MG954188
Xanthocarpia ferrarii	Vondrák 18686	Russia, Tuva	limestone	50.0655, 95.5856	1530	MG954189
Xanthocarpia ferrarii	Vondrák 18230	Russia, Khakasia	limestone	54.6633, 89.8430	410	MG954190
Xanthocarpia ferrarii	Vondrák 18196	Russia, Tuva	concrete	51.1992, 95.5258	840	MG954191
Xanthocarpia interfulgens	Vondrák 18155	Russia, Altai	limestone	50.1078, 88.4578	2650	MG954186
Xanthocarpia interfulgens	Vondrák 18194	Russia, Khakasia	limestone	54.3189, 90.6105	470	MG954187
Xanthocarpia tominii	Vondrák 12711	Russia, Altai	plant debris	50.1382, 88.4935	3050	MG954185
Xanthomendoza trachyphylla	Vondrák 18028	Russia, Altai	limestone	50.1078, 88.4578	2650	MG954172
Xanthomendoza trachyphylla	Frolov 214	Russia, Altai	limestone	50.1382, 88.4935	2700	MG954173
Xanthomendoza trachyphylla	Frolov 140	Russia, Altai	lime-rich schist outcrops	50.0817, 88.7189	2000	MG954174
Xanthomendoza ulophyllodes	Vondrák 18145	Russia, Altai	bark of *Populus*	51.1378, 87.8355	500	MG954175
Xanthomendoza ulophyllodes	Vondrák 18148	Russia, Altai	soil bryophytes	50.9994, 88.0585	600	MG954176
Xanthomendoza ulophyllodes	Vondrák 18159	Russia, Altai	siliceous rock	51.1799, 87.7729	500	MG954177
Xanthomendoza ulophyllodes	Vondrák 18696	Kemerovo region	bark of *Populus tremula*	55.6303, 86.4500	350	MG954178

Four-group environmental classification of habitats

Each sampling site was classified as one of: (1) humid non-alpine; (2) humid alpine; (3) arid non-alpine; (4) arid alpine. (The class of each sampling site is listed in Appendix 1.) This is a natural classification, readily apparent in the field because the lichen communities in each class are very different. It is further supported by the detailed classification of Altai vegetation proposed by Kamelin *et al.* (2005). Each of our classes corresponds to a group of several of their vegetation units.

(1) Humid non-alpine. Sites in habitats where natural vegetation is formed by any kind of forest or tall-herb grassland below timber line (humid vegetation types of Kamelin *et al.* 2005). Rocks surrounded by these vegetation types also belong here, but rocks covered by well developed steppe plant communities are considered arid, even when in contact with forest or tall-herb grassland. This category covers most of the studied territory north of the steppes in inner Altai and Tyva with the exception of the dry Yenisey basin surrounding Abakan.

(2) Humid alpine. Sites above timber line. Vegetation is formed by various types of tundra (lichen-moss and *Dryas* tundra communities sensu Kamelin *et al.* 2005) with various subalpine to alpine shrubs (e.g. *Betula rotundifolia*, *Empetrum nigrum*, *Salix* spp., *Vaccinium* spp.) or by alpine herbal vegetation; steppe or cryoxerophylous plants are absent or uncommon. Communities with sparse and low trees at the timber line, in the subalpine altitudinal belt, also belong here. The height of the timber line generally varies from 1700–1800 m in the north of the region to 2200–2300 m in the south (Kuminova 1960; Kamelin 1998), though locally it may be below 1500 m. This class of vegetation occurs above timber line in the forest zone of Altai and Western Sayan.

(3) Arid non-alpine. Sites covered by vegetation of arid and semiarid types according to Kamelin *et al.* (2005), but without or with only few cryoxerophilous grassland vegetation elements (see below for details). General habitats of this category are steppes and deserts with various rocky outcrops at lower altitudes; the upper limit is at about 1500 m. We include here (a) rocks with dry grasslands and scrubs in the northern foothills of Altai and in the lowlands north of Western Sayan, (b) southern steppe slopes in the forest-steppe zone of Altai and Western Sayan, (c) the lower parts of Kuray steppe, (d) cliffs with dry grasslands and scrubs at lower altitudes in large basins in Tyva: basins of Bol'shoy Yenisey, Maly Yenisey and Ubsunur.

(4) Arid alpine. Steppes or deserts above the arid non-alpine zone, i.e. above about 1500 m. Alpine vegetation in arid regions is mainly formed by cryoxerophilous grassland types: e.g. *Kobresia* communities, cryoxerophilous cushion plant formations and cryoxeropetrophytic communities (see Kamelin *et al.* 2005 for plant species compositions). Steppe vegetation elements from lower altitudes may also occur here. Arid alpine sites are well developed in the dry south-eastern part of the Russian Altai, such as in Chuya steppe, but fragments are present in, for example, the upper parts of Kuray steppe in Altai or around the Ubsunur basin in Tyva.

Calculation of accumulation curves

Species accumulation curves were drawn according to Colwell *et al.* (2004). They are a series of means and standard deviations of number of species for increasing number of sampling sites. (Standard deviations not depicted in Figure 3 to maintain clarity). We used the method "exact" implemented in the 'specaccum' function, package 'vegan' for R (R developmental core team, 2008).

Identifications of anthraquinones

Specimens of *Rufoplaca* and '*Caloplaca*' *epithallina* were analyzed by LC-MS (ultra performance liquid chromatography and mass spectrometry). Apothecia (the only part containing anthraquinones in the analysed lichens) were extracted in methanol using an ultrasonic device. LC-MS Methods followed Valný *et al.* (2016) with a few modifications: the analyses were performed under a linear gradient program (min/%B) 0/5, 1.5/5, 12.5/58 followed by a 1.5-minute column clean-up (100% B) and 1.5-minute equilibration (5% B); the total analysis time was 20 minutes. The mass spectrometer operated in the W mode. Individual metabolites were identified in UV (DAD detector) and in the negative or positive mode of electrospray ionisation (ESI). Whereas most anthraquinones are visible in the negative mode, parietin is more distinct in the positive mode.

Results

Regional species richness and diversity in supraspecific taxa

Teloschistaceae is species-rich in the Altai-Sayan region. We recorded 103 species in 31 genera. 46 species in 14 genera belong to *Xanthorioideae*, 57 species in 17 genera to *Caloplacoideae*; no members of *Teloschistoideae* were recorded (Fig. 2). As shown in Table 2, almost half of the genera are represented by only one species in the region, but a few genera are species-rich; only *Calogaya* and *Pyrenodesmia* have more than 10 recorded species.

FIGURE 2. Classification within Teloschistaceae displayed on the single locus ITS tree (2372 sequences included, maximum likelihood method, branches with the bootstrap support ≥ 70% are thick). Genera and groups putatively on generic level are collapsed into single terminals. Groups occurring in southern Siberia are linked with red names on the right. Pale grey link: genera with 1–2 species; medium grey, 3–5 species; black, 6 and more species.

TABLE 2. Species richness within genera of Teloschistaceae in the Altai-Sayan region and diversity in basic functional traits.

Genera or groups putatively on generic level	Species richness	Species richness in categories of habitats								Number of species with traits		
		arid alpine	arid non-alpine	humid alpine	humid non-alpine	arid	humid	alpine	non-alpine	foliose or fruticose thallus	thick crust with thick medulla	vegetative diaspores
in *Xanthorioideae*												
Amundsenia	1	0	0	1	0	0	1	1	0	0	0	0
Athallia	5	2	2	2	3	5	4	3	3	0	0	0
Calogaya	11	8	6	2	3	11	5	10	6	0	0	2
Flavoplaca	2	0	2	0	2	2	2	0	2	0	0	1
Pachypeltis	4	4	0	1	0	4	1	4	0	0	2	0
Parvoplaca	1	0	0	1	0	0	1	1	0	0	0	0
Polycauliona	1	0	1	0	1	1	1	0	1	1	0	1
Rusavskia	6	3	6	4	3	6	6	4	4	5	1	1
Xanthocarpia	5	5	5	2	3	5	5	5	5	0	0	1
Xanthomendoza	3	1	1	0	2	2	2	2	2	2	1	2
Xanthoria	1	0	0	0	1	0	1	0	1	1	0	0
'Caloplaca' anularis group	4	4	1	0	0	4	0	4	1	0	4	0
'*Caloplaca' ahtii*	1	0	0	0	1	0	1	0	1	0	0	0
'Caloplaca' raesaenenii	1	0	1	0	0	1	0	1	1	0	0	0
total	46	27	25	13	19	41	30	35	27	9	8	8
in *Caloplacoideae*												
Blastenia	3	0	0	2	2	0	3	2	2	0	0	2
Bryoplaca	2	0	0	2	0	0	2	2	0	0	0	0
Caloplaca	8	1	3	3	5	3	8	3	6	0	0	5
Gyalolechia sensu lato	7	3	5	1	3	7	4	4	6	0	0	4
Leproplaca	3	1	1	1	1	2	1	2	1	0	0	3
Pyrenodesmia	11	6	8	2	2	10	3	8	8	0	2	4
Rufoplaca	5	1	1	3	4	1	5	3	4	0	0	0
Seirophora	2	1	2	0	0	2	0	1	2	2	0	0
Shackletonia	1	1	1	1	1	1	1	1	1	0	0	0
Squamulea	1	0	1	0	0	1	0	0	1	0	0	0
Variospora	2	2	2	0	0	2	0	2	0	0	0	0
'*Caloplaca' exsecuta* group	3	0	0	3	1	0	3	3	1	0	0	1
'*Caloplaca' conversa/ conglomerata* group	1	0	1	0	0	1	0	0	1	0	0	0
'*Caloplaca' haematites/ aractina* group	1	1	0	0	0	1	0	1	0	0	0	0
'*Caloplaca' xerica* group	5	1	2	1	3	2	4	2	4	0	0	3
'*Coccinodiscus'* group	1	1	1	1	0	1	1	1	1	0	0	0
unknown '*Caloplaca'* sp.	1	0	0	0	1	0	1	0	1	0	0	0
total	57	19	28	20	23	34	36	35	39	2	2	22
species in Teloschistaceae	103	46	53	33	42	75	66	70	66	11	10	30
genera in Teloschistaceae	31	18	21	17	19	23	24	24	25	5	5	13

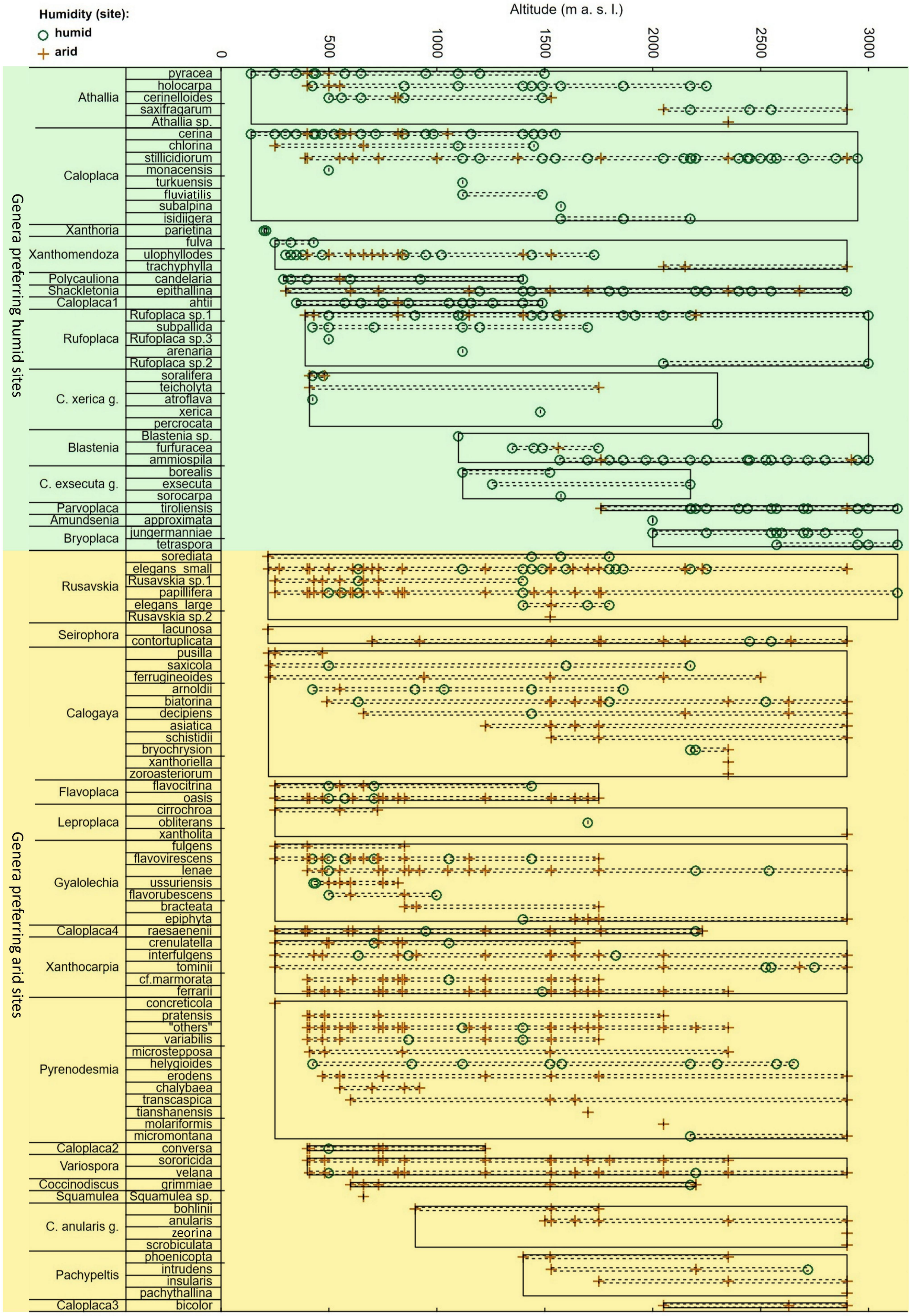

FIGURE 3. Species and genera of Teloschistaceae recorded in southern Siberia sorted according to their preference to humidity (legend in the upper left corner) and altitude.

Significant extensions of known geographical range

'*Caloplaca*' *pratensis* is new to **Eurasia**. Three species are new to **Asia**: *Caloplaca turkuensis*, '*Caloplaca*' *helygeoides* and '*C.*' *soralifera*. Twelve taxa are new to **Russia**: *Blastenia furfuracea*, *Calogaya ferrugineoides*, *C. xanthoriella*, *C. zoroasteriorum*, '*Caloplaca*' *zeorina*, '*C.*' aff. *tianshanensis*, *Pachypeltis insularis*, *P. intrudens*, *P.* aff. *pachythallina*, *P. phoenicopta*, *Rusavskia dasanensis* and *Variospora sororicida*. Nine species are new to **Siberia**: *Calogaya pusilla*, *Caloplaca monacensis*, '*Caloplaca*' *anularis*, '*C.*' *atroflava*, '*C.*' *xerica*, *Flavoplaca oasis*, *Pyrenodesmia concreticola*, *P. erodens* and *Xanthocarpia ferrarii* (sensu lato). Two species are new to **Kazakhstan**: *Blastenia furfuracea* and '*Caloplaca*' *ahtii*. Nine species are new to **China**: *Athallia saxifragarum*, *Blastenia furfuracea*, *Caloplaca chlorina*, *C. stillicidiorum*, '*Caloplaca*' *epithallina*, '*C.*' *helygeoides*,'*C.*' *raesaenenii*, *Gyalolechia epiphyta* and *Parvoplaca tiroliensis*. Two species are new to **Xinjiang**: *Blastenia ammiospila* and *Bryoplaca tetraspora*. Outside the investigated region *Pachypeltis phoenicopta* is new to **Europe** (Spain, Sierra Nevada); we also report the first reliable record of *Pachypeltis insularis* in **Greece** (Mt Olympus).

Species and generic richness in four categories of habitats (defined in Methods)

The total number of species recorded in all habitat categories is calculated in Table 2. Accumulation curves (Fig. 4A) demonstrate the highest species richness in the category arid non-alpine, but they suggest that arid alpine habitats have even more species (fewer sites were sampled, but the accumulation curve is steep). Both humid categories have fewer species.

If we consider only species with 100% fidelity to a single category of habitats (i.e. species not recorded in other categories), the curves have slightly different shapes (Fig. 4B) and the curve of arid alpine habitats becomes steeper. This suggests both that arid alpine sites have the highest number of faithful species and that we failed to detect a high proportion of those species. Humid habitats again have fewer species, but the humid alpine curve is above humid non-alpine, indicating that more species are confined to humid alpine sites.

Preferences of species and genera for temperature (expressed by altitude) and humidity differ substantially (Fig. 3). Three genera are confined to arid alpine habitats: *Pachypeltis*, the '*Caloplaca*' *anularis* group, and the '*Caloplaca*' *bicolor* group (with a single species in the region). Five genera strongly prefer humid alpine habitats: *Amundsenia*, *Blastenia*, *Bryoplaca*, *Parvoplaca* and the '*Caloplaca*' *exsecuta* group. Some genera represented by a single species in the region are confined to other habitat categories, e.g. *Xanthoria* to humid non-alpine and *Squamulea* to arid non-alpine sites. Most species-rich genera include species with various preferences.

42 species in 19 genera were recorded in **humid non-alpine** sites. Most of them have a broad geographic range in the temperate zone, including Europe. The few exceptions are *Caloplaca fluviatilis* (only known from this region), '*Caloplaca*' *ahtii* and '*C.*' *borealis* (both usually boreal, but with scattered records elsewhere in Europe), and *Gyalolechia ussuriensis* (almost restricted to the Far East). **Characteristic genera:** *Athallia*, *Caloplaca*, *Rufoplaca*, *Xanthoria*.

33 species in 17 genera are known from **humid alpine** sites. Most of them have a broad arctic-alpine distribution and are also known from the European mountains. Examples include *Amundsenia approximata*, *Blastenia ammiospila*, *Bryoplaca tetraspora*, *Calogaya bryochrysion*, and '*Caloplaca*' *exsecuta*. Other species are broadly distributed in Eurasian mountains, but are not known from the Arctic (e.g. *Caloplaca subalpina* and '*Caloplaca*' *percrocata*). Noticeably fewer species of *Xanthorioideae* were recorded in this category (13 species) than in the arid alpine category (27), but the numbers are almost equal for *Caloplacoideae* (Table 2). **Characteristic genera:** *Bryoplaca*, *Parvoplaca*, and the '*Caloplaca*' *exsecuta* group.

53 species in 21 genera were recorded in **arid non-alpine** sites. Although this is the most species rich category, only a few species are restricted to it: e.g. *Gyalolechia fulgens* and *Seirophora lacunosa*. Most of the species are also commonly found in other categories and some species are even more typical for other categories, e.g. epiphytes of the humid non-alpine zone (e.g. *Athallia pyracea*, *Polycauliona candelaria*) or arid alpine species (e.g. *Seirophora contortuplicata*, '*Caloplaca*' cf. *bohlinii*). **Species-rich genera:** *Calogaya*, *Rusavskia*, *Pyrenodesmia*, *Xanthocarpia*.

46 species in 18 genera were recorded in **arid alpine** sites. The Teloschistaceae of these sites is distinctive and has strong links to the large areas of dry continental Asia. '*Caloplaca*' *bicolor* and species of the '*Caloplaca*' *anularis* group (except '*C.*' *anularis* itself) are only known from continental Asia. *Pachypeltis* is also typical of dry continental Asia, though some species are known from the Arctic (e.g. *P. castellana*) and dry alpine sites in Europe: *P. insularis* in the continental Alps and on Mt Olympus, Greece; *P. phoenicopta* in the Sierra Nevada, Spain. Other taxa frequent in arid alpine habitats and typical of (but not restricted to) dry continental Asia are *Calogaya*, *Rusavskia* and *Xanthomendoza trachyphylla*. **Species-rich genera:** *Calogaya*, *Pachypeltis*, *Pyrenodesmia*, *Xanthocarpia*, '*Caloplaca*' *anularis* group.

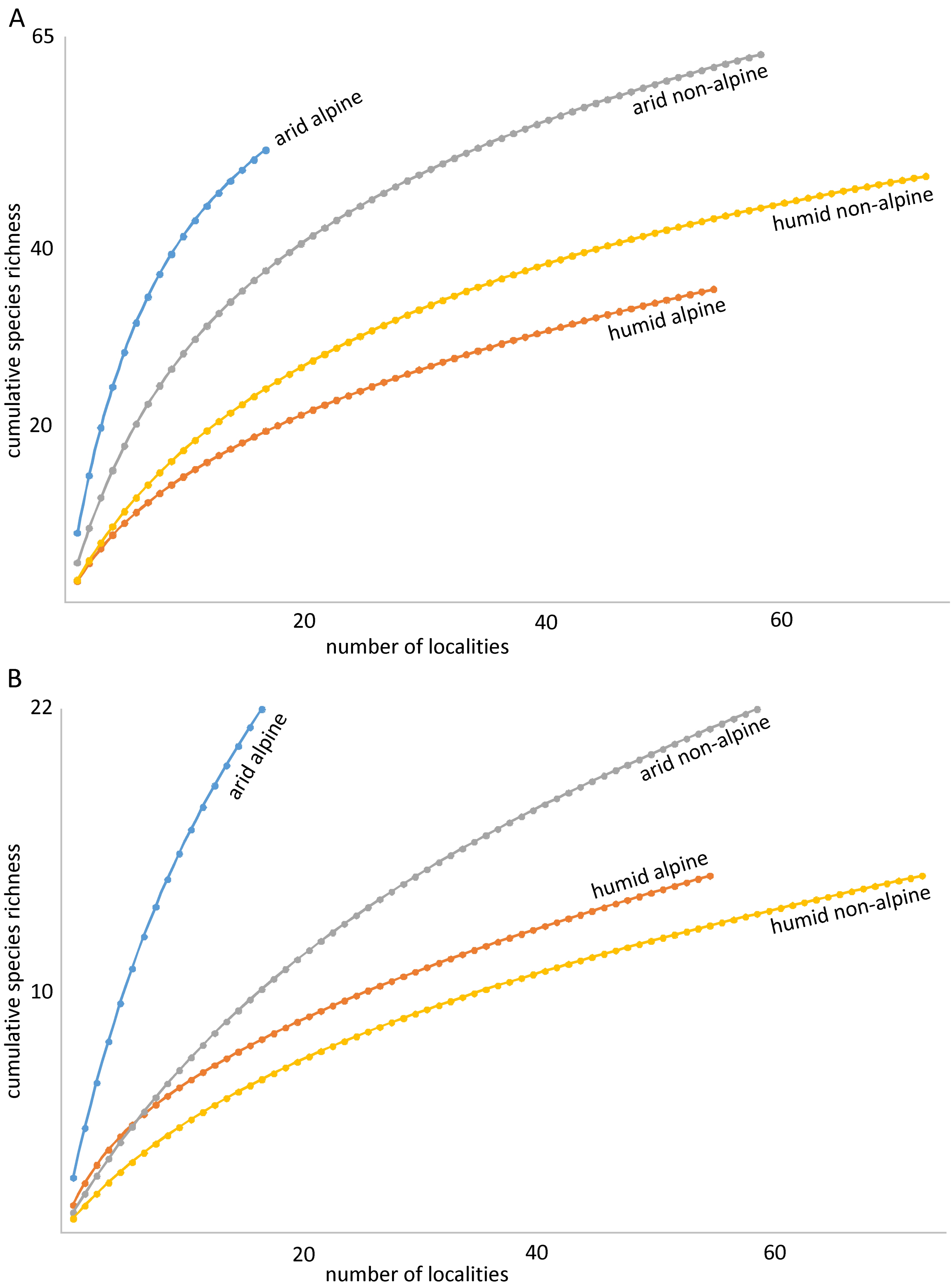

FIGURE 4. Species richness accumulation curves for localities in the four categories of habitats. A, all species included; B, only species recorded in a single category included.

Diversity in morphological and ecological traits

Species from the Altai-Sayan region show most of the variability in thallus appearance, reproductive modes and secondary chemistry known in Teloschistaceae, though some traits are rare and only occur in specific conditions. Table 2 shows frequencies of three important traits (thallus complexity, thickness of crustose thalli and presence of vegetative diaspores) in the genera.

Humid non-alpine sites have 15 species with vegetative diaspores. About 40% of the species (16 of 42) are epiphytic, either with foliose thalli (4 species) or with crustose thalli that are usually reduced, at least partly endophloedal. Thallus morphology falls into two groups, both of which usually have a thin thallus: (1) foliose lichens (7 species; genera *Polycauliona*, *Rusavskia*, *Xanthomendoza*, *Xanthoria*) with developed lower and upper cortex, but never distinctly thickened, and (2) crustose lichens. Most crustose lichens have a reduced indistinct thallus. Even in the few crustose species with a well-developed epilithic/epiphloedal thallus (e.g. *Gyalolechia flavorubescens*, *G. flavoviresens*) the thallus is always thin (usually <100 µm thick) with indistinct cortex and medulla. Most crustose lichens are without anthraquinones in the thallus. Lichenicolous lichens are exceptional, only *Rufoplaca* sp. 3 and '*Caloplaca*' *epithallina*. **Characteristic traits:** (1) vegetative diaspores, (2) foliose growth form, (3) epiphytic occurrence, (4) thin epiphloedal/epilithic or endopholoedal/endolithic crustose thalli.

Humid alpine sites are inhabited by crustose Teloschistaceae (only two foliose species, *Rusavskia elegans* and *Xanthomendoza ulophyllodes*, occasionaly recorded). The thallus is usually thin, medulla and cortex are usually poorly developed. Anthraquinones are absent from the thallus in most species. Vegetative diaspores occur in 7 species. Epiphytes (7 species) are represented mainly by species on bryophytes and plant debris; they usually have reduced thalli. On all substrates thalli are often spatially restricted to small spots (well seen in *Amundsenia approximata*). Lichenicolous lichens ('*Caloplaca*' *epthalllina* and '*C.*' *grimmiae*) occur but are rare. **Characteristic traits:** (1) thin crustose thalli, (2) thalli lacking anthraquinones, (3) reduced thalli, commonly muscicolous.

Arid non-alpine sites have 12 species with vegetative diaspores. Epiphytic species are few (7) and they have small thalli: reduced crustose or rarely small foliose. Most of them occur on twigs of steppe shrubs, but two prefer bryophytes and plant debris (*Caloplaca stillicidiorum* and '*Caloplaca*' *raesaenenii*). Some species are restricted to soil and strongly weathered rock; they include crustose lichens (e.g. *Gyalolechia fulgens*) and fruticose *Seirophora lacunosa*. Epilithic Teloschistaceae are mostly crustose, only 5 species (of *Rusavskia)* are foliose. The crustose species usually have thin epilithic or endolithic thalli, often reduced areally to just small spots (e.g. *Squamulea* sp.). The thallus of most species is pigmented by anthraquinones, but some *Caloplacoideae* have Sedifolia-grey (e.g. *Pyrenodesmia*, '*Caloplaca*' *conversa*) or other pigments (e.g. '*Caloplaca*' *grimmiae*). The thick crusts commonly seen in arid alpine sites are rare here (only a few *Pyrenodesmia* species and *Gyalolechya lenae*). Some lichenicolous lichens occur; the most common was *Variospora sororicida*, usually on species of *Pyrenodesmia*. **Characteristic traits:** (1) spatially reduced and thin yellow crustose thalli, (2) growth on soil, (3) lichenicolous life style.

Arid alpine sites are poor in lichens with vegetative diaspores (5 species), in epiphytic species (5 species, mainly on dry twigs of shrubs), and in macrolichens (3 foliose species in *Rusavskia* and the fruticose *Seirophora contortuplicata*). Crustose lichens often form thick thalli (>> 100 µm thick) with very thick medulla and cortex (12 species, see Table 2). The cortex sometimes expands into the algal layer to form cortex cones or fungal stacks (e.g. in '*Caloplaca*' *scrobiculata* and '*C.*' *molariformis*; see Vondrák & Kubásek 2013 for details). Some crusts are extensive (e.g. *Xanthomendoza trachyphylla* and '*Caloplaca*' *anularis*), others are spatially restricted to small spots. The latter are often lichenicolous (*Variospora sororicida*, all *Pachypeltis* spp., '*Caloplaca*' *epithallina* and '*C.*' *grimmiae*). **Characteristic traits:** (1) thick crustose thalli, (2) extensive yellow crusts, (3) lichenicolous life style, (4) absence of vegetative diaspores.

Discussion

Altai-Sayan Teloschistaceae diversity is linked to four Eurasian floral elements

Teloschistaceae in the Altai-Sayan region includes four main floral elements: (1) boreal-montane, (2) arctic-alpine, (3) xerophilous Eurasian, and (4) xerophilous Central Asian. A Mediterranean element is absent. The Far Eastern element is represented only by *Gyalolechia ussuriensis* (Vondrák *et al.* 2016a) and *Squamulea* sp. (See the Taxonomy part for the latter species.)

(1) Boreal Teloschistaceae (e.g. *Athallia cerinelloides*, '*Caloplaca*' *ahtii* and '*C.*' *borealis*) are typical of forested areas throughout the region. Most of these species tend to have continuous ranges towards the more northern taiga zone (Urbanavichus 2010) and they are broadly distributed in northern Eurasia.

(2) Arctic-alpine species are typical of humid alpine sites. These species also have large geographic ranges including the circumpolar Arctic and temperate Eurasian and North American mountains. Throughout much of Eurasia, alpine sites, though widely separated, have similar alpine Teloschistaceae. In this respect Altai is quite similar to the Caucasus, 3000 km away, and to the even more distant European mountains. Presumably this similarity is a result of past glaciations, when arctic-alpine habitats must have covered larger areas than today.

(3) The xerophilous Eurasian group includes broadly distributed species of forest-steppe or steppe habitats (e.g. '*Caloplaca*' *conversa*, '*C.*' *raesaenenii*, '*C.*' *teicholyta* and '*C.*' *xerica*). Many of them are regionally common and may occur in xerothermic spots, such as south-facing rocks, deep in the zone of humid forests (observations from numerous Eurasian regions).

(4) The Altai-Sayan region lies on the northern edge of the large part of Asia with a dry, continental climate, so it is not surprising that lichens restricted to dry continental Asia are well represented in Altai-Sayan. This element of the biota is difficult to assess, because the Teloschistaceae of Central Asia are not well known. Although many species have been described from central Asia, e.g. Brotherus 1897, Wainio 1904, Magnusson 1940, 1944, Poelt & Hinteregger 1993, Kondratyuk *et al.* 2002, Kondratyuk & Kudratov 2003, Søchting & Figueras 2007, most were described from one or just a few localities and their geographic range and ecology is unknown. However, some observations are possible. Typical Central Asian genera are *Pachypeltis* (Arup *et al.* 2013), also known from the Arctic and from the alpine zone of temperate regions, and the '*Caloplaca*' *anularis* group, which is confined to dry alpine habitats in continental Asia except for the more widely distributed '*C.' anularis* itself. Central Asian species generally prefer arid alpine sites, and often occur at very high altitudes, but they are absent from the Arctic, except for the broadly distributed *Xanthomendoza trachyphylla*. Numerous Central Asian lichens are thick crusts with a distinct cortex and thick medulla (Magnusson 1940, 1944); some species form algal and fungal stacks (Vondrák & Kubásek 2013). This trait, which is not restricted to Teloschistaceae, has probably arisen in dry Central Asia because the distinctive climate of that region has been stable for a long period of time. It does not occur in species of other floral elements in the Altai-Sayan region.

The Alps have a distinct species composition and are richer in species

Because Teloschistaceae have not been adequately studied in most of Eurasia, we can make a meaningful comparison of Altai-Sayan only with the European Alps, which are by far the best studied mountains of Eurasia. They have been surveyed since the 18th Century, by lichenologists from various European countries. Nimis *et al.* (2018) published an annotated checklist of their lichens which includes 198 taxa (species and infraspecific units) of Teloschistaceae, though we consider 28 of them to be doubtful taxa, and we would reduce a further 10 names to synonymy. Using the remaining 160 taxa we can compare the Alps and Altai-Sayan (Table 3).

TABLE 3. Species-richness within subfamilies and genera of Teloschistaceae. Comparison between the Altai-Sayan region and the Alps. Data from Alps mostly adopted from Nimis *et al.* (2018). We also involved our experiences; e.g. in the Alps, we expect more or fewer species in some genera.

Genera or groups putatively on generic level	Species richness	
	Altai-Sayan region	Alps
in *Xanthorioideae*		
Amundsenia	1	1
Athallia	5	8
Calogaya	11	11 (overestimated)
Flavoplaca	2	14
Pachypeltis	4	3
Parvoplaca	1	1
Polycauliona	1	5
Rusavskia	6	4
Solitaria	0	1
Xanthocarpia	5	9
Xanthomendoza	3	5

...continued on the next page

TABLE 3. (Continued)

Genera or groups putatively on generic level	Species richness	
	Altai-Sayan region	Alps
Xanthoria	1	2
'Caloplaca' anularis group	4	1
'*Caloplaca' ahtii*	1	0
'Caloplaca' coccinea group	0	2
'Caloplaca' raesaenenii	1	1
'Caloplaca' ulcerosa/substerilis group	0	1 (underestimated)
total	**46**	**67**
in *Caloplacoideae*		
Blastenia	3	11
Bryoplaca	2	4
Caloplaca	8	7
Gyalolechia sensu lato	7	12
Huneckia	0	1
Leproplaca	3	5
Pyrenodesmia	11 (underestimated)	8 (underestimated)
Rufoplaca	5	7
Seirophora	2	1
Shackletonia	1	2
Squamulea	1	1
Variospora	2	8
'Caloplaca' asserigena	0	1
'*Caloplaca' conversa/ conglomerata* group	1	2
'*Caloplaca' exsecuta* group	3	4
'Caloplaca' demissa	0	1
'Caloplaca' fuscorufa	0	1
'*Caloplaca' haematites/ aractina* group	1	2
'Caloplaca' lucifuga	0	1
'Caloplaca' obscurella group	0	2
'*Caloplaca' xerica* group	5	9
'*Coccinodiscus'* group	1	1
unknown *'Caloplaca'* sp.	1	0
total	**46**	**91**
in *Teloschistoideae*		
Cerothallia	0	1
Teloschistes	0	1
little known, often dubious species without molecular data // names in Nimis *et al.* (2018) not accepted by us	0	28 // 10
species in Teloschistaceae	**92**	**160** (?+28)
genera in Teloschistaceae	**31**	**37**

The Alps have more recorded species (160 accepted species) than Altai-Sayan (103). More sampling in Altai-Sayan would certainly shrink that gap; for example, we visited few humid alpine sites with base-rich siliceous rocks and no humid alpine limestone, so species like '*Caloplaca*' *fuscorufa*, '*C.*' *livida*, '*C.*' *nivalis* and '*C.*' *tornoensis* might be present in Atai-Sayan, though not recorded by us. However, we doubt that the gap would shrink to zero. Some ecological groups known from the Alps were not recorded in Altai-Sayan: (1) epiphytic species preferring neutral bark of broad-leaf trees, such as *Acer*, *Quercus* and *Tilia* (e.g. *Caloplaca substerilis*, '*Caloplaca*' *lucifuga* and '*C.*'

obscurella); (2) oceanic species (e.g. *Teloschistes chrysophthalmos* and '*Caloplaca*' *asserigena*); (3) species confined to the Mediterranean climate (e.g. *Huneckia pollinii*, '*Caloplaca*' *aegatica*, '*C.*' *haematites* and several species of *Blastenia*). Genera known to be rich in the Mediterranean basin, *Blastenia*, *Flavoplaca*, *Variospora* and the '*Caloplaca*' *xerica* group have significantly more species in the Alps (Table 3).

Some genera have about the same number of species in each region: *Athallia*, *Calogaya*, *Caloplaca*, *Pyrenodesmia*, *Rufoplaca* and *Xanthocarpia*. For *Athallia* and *Caloplaca* that is because basically the same species are present in each region; these genera include broadly distributed, often Holarctic species that are common in various habitats. In contrast, species of *Pyrenodesmia* and *Xanthocarpia* largely differ between the regions, because these genera are divided into species confined to continental regions and species preferring the Mediterranean climate (our unpublished data).

Some genera are more species-rich in the Altai-Sayan region: *Pachypeltis*, *Rusavskia*, *Seirophora* and the '*Caloplaca*' *anularis* group. The centre of diversity for these genera appears to be dry continental Asia, and only a few of their species occur in Europe, often in spots with a dry climate (e.g. *Pachypeltis insularis*, *Rusavskia sorediata*, *Seirophora contortuplicata* and '*Caloplaca*' *anularis*). Only *Rusavskia elegans* (sensu lato) is more frequent and broadly distributed in Europe.

Conclusions

In the Altai-Sayan region, we recorded 103 species of Teloschistaceae. Dry habitats have more species (75 recorded and 60 preferring these habitats) than humid habitats (66 recorded, 40 preferring). Dry habitats are inhabited predominatly by a xerophilous Central Asian floral element, but humid habitats by boreal-montane and arctic-alpine species. Arid non-alpine habitats are the most rich in species, followed by arid alpine, humid non-alpine and humid alpine. Each of these four habitat types has a characteristic species composition with particular traits. A thick crustose thallus with thick medulla and cortex is the most distinctive trait; it is restricted to arid alpine habitats.

In some genera, the species composition is similar to that of the European mountains. Other genera are well represented in Central Asia, but largely absent in Europe. The European mountains adjacent to the Mediterranean basin have more species than the Altai-Sayan region, partly due to enrichment by Mediterranean and oceanic species that are absent from the Altai-Sayan region.

Taxonomy

Amundsenia

One epilithic species recorded in the region. It has reduced yellow thallus surrounding small yellow apothecia; vegetative diaspores are absent; non-chlorinated anthraquinones are present in thallus and apothecia. Literature: Søchting *et al.* (2014).

Amundsenia approximata: single record from altitude 2000 m (specimen Vondrák 18142) in humid alpine site in Altai. Substrate: siliceous rock. Identity of the specimen was confirmed by the ITS sequence. Few records are known outside Arctic and Scandinavia (Nimis *et al.* 2018; Swiss Alps). Ascospores in our specimen are (9–) 12.5 (–16) × (4–) 5 (–7) µm, which is distinctly larger than reported by Hansen *et al.* (1987) [8–11×3.5–4.5 µm] and Søchting *et al.* (2014) [11±1.5×4±1.5 µm], but other characters (including thin ascospore septa), ecology and ITS barcode support its identification as *A. approximata*.

Athallia

Five species recorded in the region. All have strongly reduced, usually indistinct thallus with apothecia and without vegetative diaspores. Four species are predominantly epiphytic but one species is typically epilithic. Literature: Arup (2009), Arup *et al.* (2013), Vondrák *et al.* (2012a, 2016b).

Athallia cerinelloides: 8 localities at altitudes 500–1530 m. Most records in the humid non-alpine class. Substrate: bark on trunks of *Larix*, *Populus* and *Salix*. (Commonly recorded on twigs, but no such records from the region.)

Athallia holocarpa: 13 localities at altitudes 400–2250 m. In all ecological classes, except for arid alpine. Substrate: siliceous rocks, boulders, pebbles (sandstone, schist, granite, etc.).

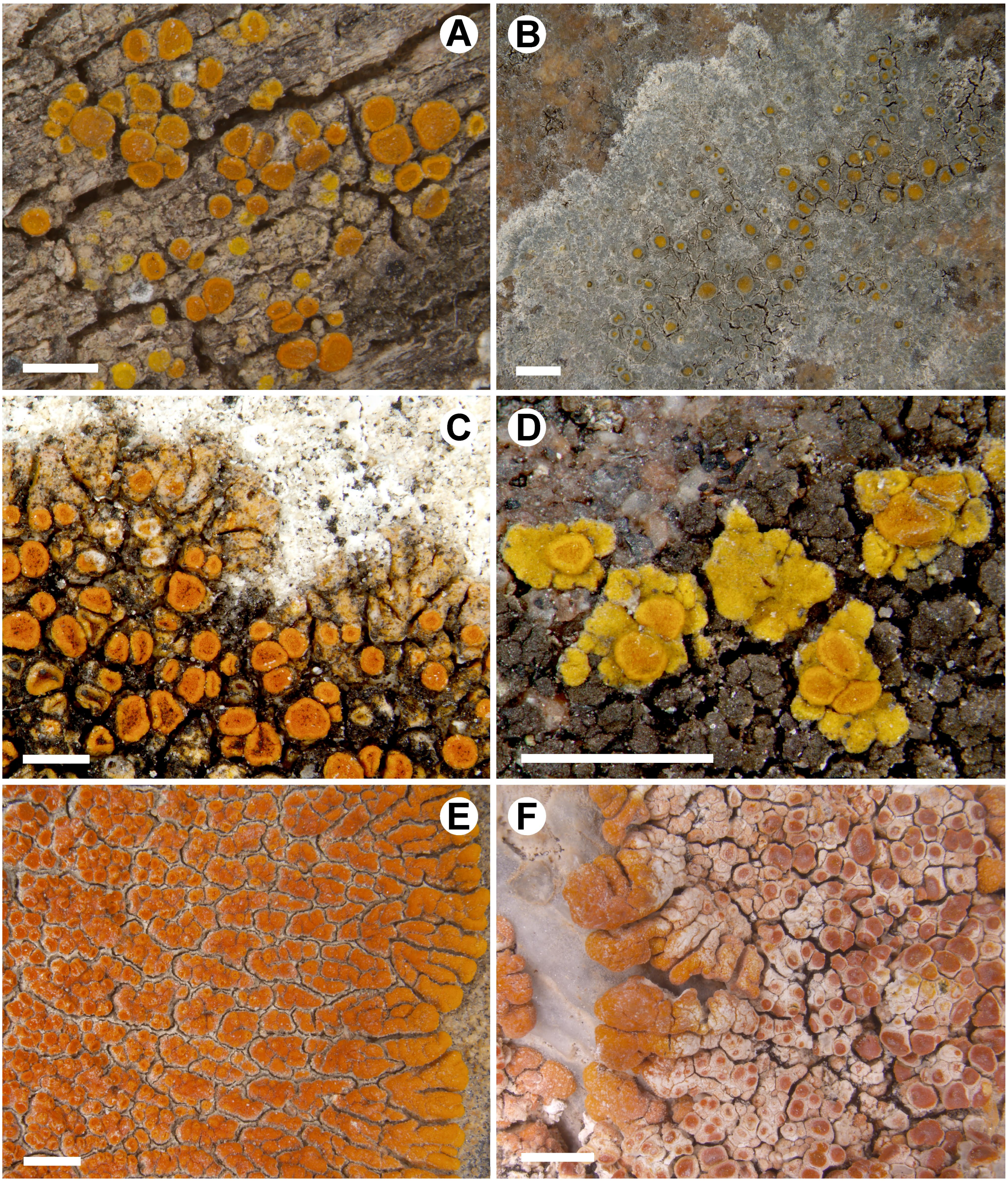

FIGURE 5. *Athallia* (A), *Caloplaca* sensu stricto (B), *Flavoplaca* (C), *Squamulea (D)* and *Xanthomendoza (*E,F). A, *Athallia* sp. (Vondrák 18073); B, holotype of *Caloplaca fluviatilis*; C, *Flavoplaca oasis* (Vondrák 18222) with indistinct marginal thallus lobes (character typical for Mediterranean-European *F. polycarpa*); D, *Squamulea* sp. (Vondrák 18682) resembling small morphotypes of *Squamulea irrubescens*; E, *Xanthomendoza trachyphylla*, a common morphotype (Vondrák 18044); F, *X. trachyphylla* with pruinose thallus on limestone (Vondrák 18028). All bars, 1 mm.

Athallia pyracea: 15 localities at altitudes 140–1200 m. In humid non-alpine and arid non-alpine classes. Substrate: bark on trunks of *Larix*, *Picea*, *Pinus*, *Populus*, single specimen on limestone (Vondrák 18039).

Athallia saxifragarum: 5 localities at altitudes 2050–2900 m. In humid alpine and arid alpine classes. Substrate: bryophytes and plant debris in alpine habitats.

Athallia sp., Fig. 5A: Recorded in a single locality in the arid alpine steppe, at altitude 2350 m, on twigs of *Lonicera* (specimens Frolov 1599, Vondrák 18073). Phenotype is similar to *A. cerinelloides* or *A. saxifragarum*, but the ITS sequence (MG954143) is more similar to sequences of *A. alnetorum* (96–97% similarity) or *A. holocarpa* and *A. cerinella* (94–96%).

Blastenia

Three epiphytic species recorded in the region. All have crustose, but sometimes indistinct areolate thallus. Apothecia are in all species, but two species also have vegetative diaspores. All species belong to a single section of *Blastenia* characterised by arctic-alpine to boreal-montane distribution (Vondrák *et al.*, unpublished). Literature: Arup & Åkelius (2009), Arup *et al.* (2013), Nimis (2016), Vondrák *et al.* (2013).

Blastenia ammiospila: 22 localities at altitudes 1570–3000 m. Most records from humid alpine habitats; exceptionally in high-montane to alpine arid habitats. Substrate: bryophytes, plant debris, alpine shrubs.

Blastenia furfuracea: 5 localities in Altai at altitudes 1350–2400 m. In humid non-alpine and subalpine habitats; forests and sparse *Larix* stands at timber line. Substrate: wood and bark of *Larix*, bark of *Betula tortuosa*. The record of *Blastenia herbidella* in Davydov & Printzen (2012a) belongs to this species.

Blastenia sp.: One specimen recorded in forest habitat in Altai at 1100 m (Davydov 11222). Substrate: bark of *Betula*. This is a distinct species which we have provisionally named "*Blastenia monticola*"; it will be formally published elsewhere (Vondrák *et al.*, in preparation). It was called *Caloplaca* cf. *herbidella* in Arup & Åkelius (2009, specimen EÅ15). Similar to *B. furfuracea*, but with vegetative diaspores 50–200 μm diam. (40–70 μm diam. in *B. furfuracea*). The two species also differ in three DNA loci (Vondrák *et al.*, loc. cit.).

Bryoplaca

Two species recorded in the alpine zone in Altai-Sayan. Both species have rather reduced crustose thallus overgrowing moss cushions or on dead plant tufts. Apothecia are abundant, vegetative diaspores missing. Literature: Arup *et al.* (2013).

Bryoplaca jungermanniae: 9 localities at altitudes 2000–2950 m, in humid alpine habitats. Substrate: bryophytes overgrowing calcareous or rarely siliceous soil.

Bryoplaca tetraspora: 4 localities at altitudes 2570–3140 m, in humid alpine habitats. Substrate: bryophytes overgrowing calcareous or siliceous soil.

Calogaya

Ten species and one infraspecific taxon recorded in the region. Thallus complexity ranges from distinctly lobate large thalli (*C. biatorina*) to strongly reduced inconspicuous thalli (e.g. *C. ferrugineoides*). Most species produce apothecia and lack vegetative diaspores, but two species (*C. bryochrysion* and *C. decipiens*) are sorediate and only occasionally produce apothecia. The genus is species rich in continental Central Asia, where it has diversified into numerous epilithic and epiphytic species (Vondrák *et al.* 2018). Literature: Arup *et al.* (2013), Gaya (2009; focused on epilithic species), Steiner & Poelt (1982; only three epiphytic species), Vondrák *et al.* (2018).

Calogaya arnoldii: 7 localities at altitudes 420–1870 m. In dry microhabitats below rocky overhangs in various ecological classes, but not recorded in arid alpine habitats. Substrate: various types of calcareous and siliceous rocks.

Calogaya biatorina: 12 localities in a broad altitude range, 490–2900 m. In all ecological classes, but most records in arid alpine habitats. Substrate: various types of calcareous and siliceous rocks.

Calogaya biatorina subsp. *asiatica*: 6 localities at altitudes 1220–2900 m. In arid, usually alpine habitats. Substrate: limestone. It is morphologically distinct from *C. biatorina* subsp. *biatorina* by thinner, densely arranged (not imbricate) marginal lobes and round inner areoles surrounded by white pruinose rims (Vondrák *et al.* 2018).

Calogaya bryochrysion: 3 localities at altitudes 2170–2350 m. In arid and humid alpine habitats. Substrate: various types of rocks, bryophytes, plant debris, stems of alpine shrubs and bark of *Populus* (i.e. a broad range of substrates). Further information in Vondrák *et al.* (2016a).

Calogaya decipiens: 5 localities in a broad altitude range, 660–2900 m, in various ecological classes, but not recorded in humid alpine habitats. Substrate: calcareous and siliceous rocks.

Calogaya ferrugineoides: 5 localities in a broad altitude range, 230–2500 m, in arid alpine and non-alpine classes. Substrate: branches of *Atriplex cana*, *Juniperus sabina*, *Lonicera* sp. and other shrubs in steppe and desert habitats, also on bark of *Populus laurifolia*.

Calogaya pusilla: 3 localities at altitudes 220–470 m, in arid non-alpine habitats. Substrate: limestone.

Calogaya saxicola s.lat.: 4 localities in a broad altitude range, 220–2180 m, in various ecological classes. Substrate: limestone or siliceous rocks, usually below overhangs. The taxonomy of *C. saxicola* is not resolved and more than one phylogenetic species are probably involved. It has a similar morphology to *C. arnoldii* (short or fully reduced thallus lobes), but *C. arnoldii* is distinct in three-loci sequence data (Vondrák *et al.* 2018).

Calogaya schistidii: 3 localities at high altitudes, 1530–2900 m, in arid alpine habitats. Substrate: bryophytes overgrowing limestone.

Calogaya xanthoriella: two records (specimens Frolov 1598 and Davydov 10857) at altitude 2350 m on twigs of *Lonicera* in arid alpine steppe and at altitude 1280 m in desert steppe on wooden stems of *Krascheninnikovia ceratoides*. It was described from China and Turkey and is distinguished from similar *C. ferrugineoides* or *C. polycarpoides* by a three-loci phylogenetic analysis (Vondrák *et al.* 2018).

Calogaya zoroasteriorum: three specimens recorded in single locality (Frolov 1597, Vondrák 10308, 18084) at altitude 2350 m on twigs of *Lonicera* in arid alpine steppe. It was described from Iran as *Caloplaca zoroasteriorum* (Kondratyuk *et al.* 2013a), but has recently been transfered to *Calogaya* (Vondrák *et al.* 2018). Specimens from Altai form a distinct clade separated from Iranian specimens of *C. zoroasteriorum* in a three-loci DNA analysis, but both sets of specimens are morphologically similar in having whitish and sorediate thallus squamules (usually without anthraquinones) with usual absence of apothecia.

Caloplaca (sensu Arup *et al.* 2013)
8 species recognized in the region. *Caloplaca* in a modern sense (Arup *et al.* 2013) is morphologically circumscribed by almost lecanorine apothecia and crustose thallus, formed by thin continuous crust or areoles, rarely tiny squamules. Apothecia are present in all species, vegetative diaspores are present (in 5 recorded species) or absent. Literature: Arup *et al.* (2013), Šoun *et al.* (2011), Vondrák *et al.* (2008).

Caloplaca cerina s.lat.: 27 localities at altitudes 140–1550 m, in humid and occasionally arid non-alpine habitats. Substrate: very common on trunks and twigs of *Populus tremula*, also on *Betula*, *Juniperus*, *Larix*, *Pinus sylvestris*, *Populus laurifolia*, *Salix* and *Sorbus*; one epilithic record (Vondrák 10405) on dust-impregnated sunny schist. Šoun *et al.* (2011) demonstrated that the morphologically circumscribed *C. cerina* is not monophyletic in the ITS tree and more phylogenetic species are presumed to exist within it. We consider the population common on *Populus* throughout Altai-Sayan region to be a single species, but the population which is common on *Pinus sylvestris* in Tyva may belong to a separate species. Specimens from *P. sylvestris* (Frolov 1805, Vondrák 18262, 18410) have distinctly darker, red apothecia and dark grey thallus resembling the Mediterranean *C. haematites*.

Caloplaca chlorina: 4 localities at altitudes 250–1450 m, in humid and arid non-alpine habitats. Substrate: siliceous and calcareous rocks, usually in damp and +/- shaded places.

***Caloplaca fluviatilis* Vondrák & I.V. Frolov, species nova**
MycoBank: MB826775
Figs: 5B, 6.

Etymology: The name refers to the ecology of the species; it occurs in rivers.

Type:—RUSSIA. Republic of Tyva: Ak-Dovurak, Alash, 2 km SE of village Ak-Sug, siliceous rocks in forest-steppe, in valley of river Mungash-Ak, alt. 1120 m, 51.4003N, 90.4448E, on siliceous stone in river, occasionally inundated, 8 July 2013, *Ivan Frolov & Jan Vondrák 18229* (holotype PRA).

Type sequence: MG954128 (ITS).

Diagnosis: Thallus thin (<100 μm thick), rimose areolate in center, film-like and effuse at margins, without vegetative diaspores. Thallus and the lecanorine apothecial margin usually pale grey, with low content of Sedifolia-grey pigment. Apothecial disc pale orange, or pale yellow when in damp and shady conditions. Its occurrence on occassionally inundated siliceous boulders is distinctive. *Caloplaca cerina* and *C. stillicidiorum* are similar but epiphytic. *Caloplaca chlorina*, occurring in similar substrates and habitats, has vegetative diaspores.

Ecology and Geography: On occasionally inundated siliceous boulders in river, in rather damp and shaded sites. Only known from two sites on southern slopes of Western Sayan in the Republic of Tyva (Russia). It is abundant in the two localities and presumably is common in rivers Ak-Sug and Kara-Sug at altitudes 1100–1500 m, in a forest-steppe zone.

Phylogeny: In the ITS tree, it belongs to *Caloplaca* sensu stricto forming a clade within the large group including *Caloplaca stillicidiorum* lineages (Fig. 6).

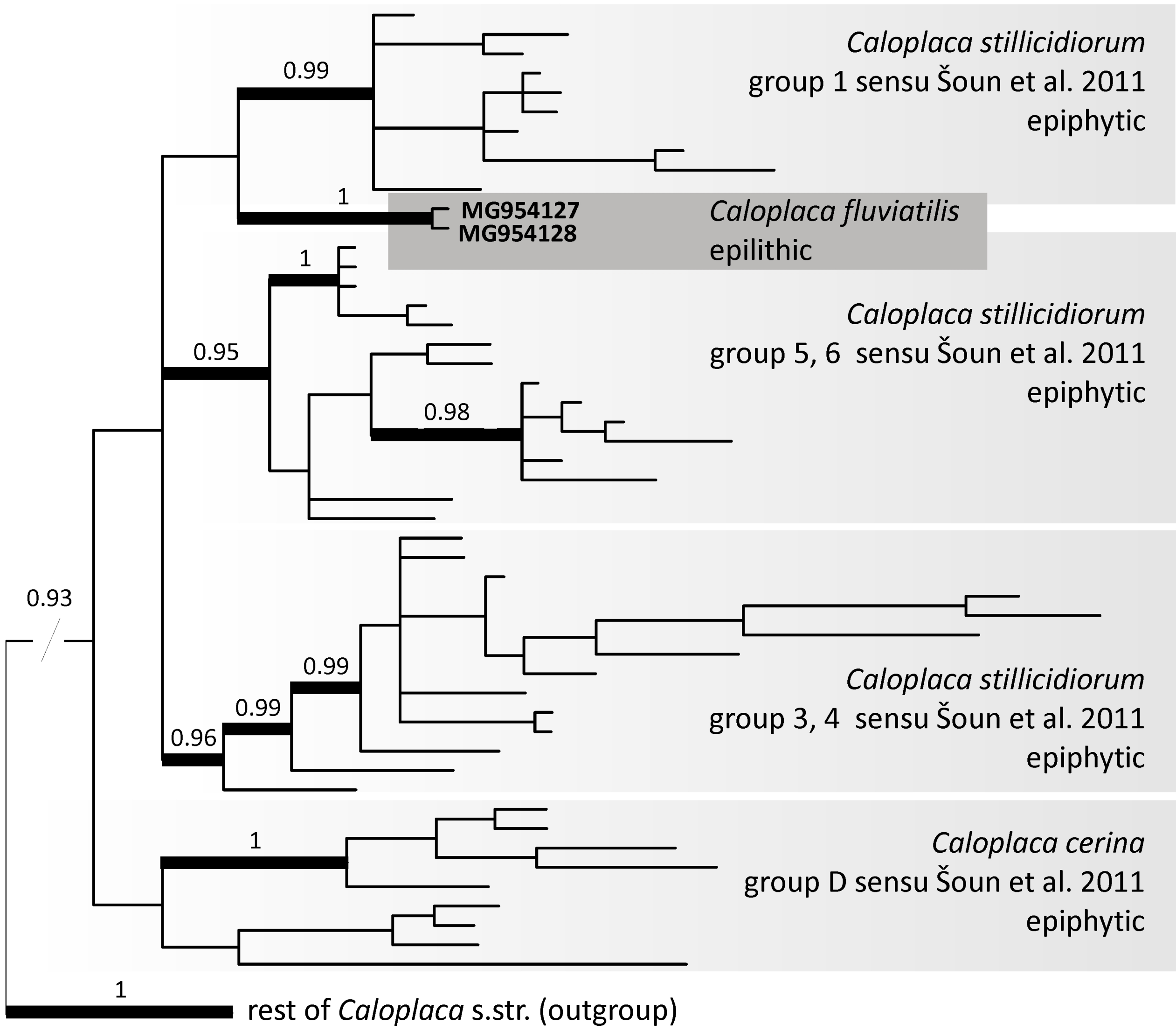

FIGURE 6. Bayesian phylogenetic reconstruction of a part of the genus *Caloplaca* (sensu stricto) using the ITS DNA locus. The epilithic *Caloplaca fluviatilis* is unresolved in polytomy with epiphytic lineages of *C. cerina* and *C. stillicidiorum*.

Taxonomy. Ecologically very distinct from all close lineages of *C. stillicidiorum* which are confined to organic substrates. Morphologically distinct from all known epilithic species by absence of vegetative diaspores, pale colour of thallus and apothecia, and film-like effuse thallus.

Paratypes: Russia, Republic of Tuva, West Sayan Mts, Ak-Dovurak, Ak-Sug, 2 km N of settlement Enge-Beldir, boulders in river Kara-Sug, alt. 1490 m, 51.618896N, 90.076410E, 8 July 2013, *Ivan Frolov 1313* (Frolov's personal herbarium), *Jan Vondrák 11104, 18213* (PRA); The type locality, 8 July 2013, *Ivan Frolov 630, 631, 634* (Frolov's personal herbarium).

Caloplaca isidiigera: 3 localities at altitudes 1570–2180 m, in humid alpine habitats. Substrate: base-rich siliceous rocks (mica-schist, sandstone). More information in Vondrák *et al.* (2016a).

Caloplaca monacensis: Once recorded at altitude 500 m in humid non-alpine habitat (specimen Vondrák 18032). Substrate: bark of *Populus* sp.

Caloplaca stillicidiorum s.lat.: 30 localities at altitudes 390–2950 m, in all ecological classes, but more frequent in dry habitats and alpine habitats. Known from various organic substrates: wood, bryophytes, twigs of shrubs in steppe and above timber line; perhaps only exceptionally on trees. Šoun *et al.* (2011) reported several groups within *C. stillicidiorum* that may be separate species. More than one group may be present in the Altai-Sayan region.

Caloplaca subalpina: Recorded once at altitude 1575 m in humid alpine habitat. Substrate: mica-schist, vertical rock faces or below overhangs. More information in Vondrák *et al.* (2016a).

Caloplaca turkuensis: Recorded once at altitude 1120 m in a forest-steppe zone (specimen Vondrák 18405).

Substrate: wood of *Larix*. Often forming grey blastidiate crusts without apothecia; perhaps more frequent in the region.

Flavoplaca

Only 2 species recorded in the region, both with crustose thallus. *Flavoplaca flavocitrina* is a broadly distributed species forming areoles or tiny squamules producing soredia; apothecia are rarely present in the material from the region. *Flavoplaca oasis* has abundant apothecia, but vegetative diaspores are absent. Literature: Arup (2006), Arup *et al.* (2013), Orange (2018), Vondrák *et al.* (2009).

Flavoplaca flavocitrina: 7 localities at altitudes 250–1440 m, in humid and arid non-alpine habitats. Substrate: calcareous and base-rich siliceous rocks. Additional information in Vondrák *et al.* (2016a).

Flavoplaca oasis: 18 localities at altitudes 250–1750 m, in humid and arid non-alpine habitats, rarely in humid alpine sites. Substrate: limestone, rarely base-rich siliceous rocks. The species has variable thallus morphology in the region. Typical morphotypes with strongly reduced thallus were found together with morphotypes with tiny yellow lobes (Fig. 5C) resembling the Mediterranean-European *F. polycarpa*.

***Gyalolechia* sensu lato**

7 species recorded in the region. All are crustose, often with thick thallus. Vegetative diaspores are present (4 species) or absent. Apothecia are known in all species, but rare in some species with vegetative diaspores (e.g. *Gyalolechia lenae*). *Gyalolechia* was defined in a broad sense by Arup *et al.* (2013) and subdivided into smaller genera by Kondratyuk *et al.* (2014a, 2017). We adopted the broad concept of the genus, but group the species into three infrageneric sections corresponding to Kondratyuk's small genera: (1) *Gyalolechia* sensu stricto including soil inhabiting lichens formerly placed in *Fulgensia*, (2) *Mikhtomia*, a group of species similar to *Gyalolechia flavorubescens* and (3) *Hanstrassia*, a group of thick xerophilous crustose lichens from continental Asia. Literature: Arup *et al.* (2013), Kondratyuk *et al.* (2014a, 2017), Søchting & Figueras (2007).

Gyalolechia bracteata (section *Gyalolechia*): 3 localities at altitudes 850–1750 m, in arid ecological classes. Substrate: calcareous soil, weathered limestone.

Gyalolechia epiphyta (section *Mikhtomia*): 5 localities at altitudes 1400–2900 m, mostly in arid ecological classes. Substrate: various types of inorganic and organic substrates; base-rich siliceous rock, calciphilous bryophytes, bark of *Populus* in dry sites. Additional information in Vondrák *et al.* (2016a).

Gyalolechia flavorubescens (section *Mikhtomia*): 4 localities at altitudes 500–1000 m, in humid non-alpine ecological class. Substrate: bark of *Populus*, *Sorbus*.

Gyalolechia flavovirescens (section *Mikhtomia*): 20 localities at altitudes 250–1750 m, in humid and arid non-alpine ecological classes plus single record in dry alpine class. Substrate: calcareous and base-rich rock (e.g. schist, gneiss).

Gyalolechia fulgens (section *Gyalolechia*): 3 localities at altitudes 250–850 m, in arid non-alpine steppes. Substrate: calcareous soil, loess.

Gyalolechia lenae (section *Hanstrassia*): 19 localities at altitudes 400–2900 m, most records from arid alpine and non-alpine habitats and exceptionally in humid ecological class. Substrate: limestone, less frequently base-rich siliceous rocks.

Gyalolechia ussuriensis (section *Mikhtomia*): 9 localities at altitudes 430–820 m, in arid and humid non-alpine classes. Substrate: bark of *Juniperus sabina*, *Larix*, *Populus*, *Salix*. Additional information in Vondrák *et al.* (2016a).

Leproplaca

3 species recorded in the region. All are crustose, sorediate, without apothecia, and confined to inorganic substrates. Literature: Arup *et al.* (2013), Nimis (2016).

Leproplaca cirrochroa: 3 localities at altitudes 250–730 m, in arid and humid non-alpine classes. Substrate: limestone.

Leproplaca obliterans: Only one specimen recorded at altitude 1600 m, in humid alpine habitat, at Buybinskiy pereval in West Sayan Mountains (Vondrák 12662). Substrate: base-rich mica-schist in glacier cirque.

Leproplaca xantholyta: Only one specimen recorded at altitude 2800 m, in arid alpine habitat, on Kuray Ridge in Altai (Vondrák 18065). Substrate: limestone, in rock crevice.

Pachypeltis (Figs 7B–F, 8)

4 species recorded in the region. All are crustose, without vegetative diaspores and with apothecia (but apothecia are rare in *P. phoenicopta*). All species have spatially reduced but usually thick areolate or squamulose thallus which is mostly lichenicolous on epilithic crustose lichens. Most species thrive in dry alpine habitats. Important diagnostic character is the amyloid (I+ blue) medulla and parts of cortex. Literature: Arup *et al.* (2013).

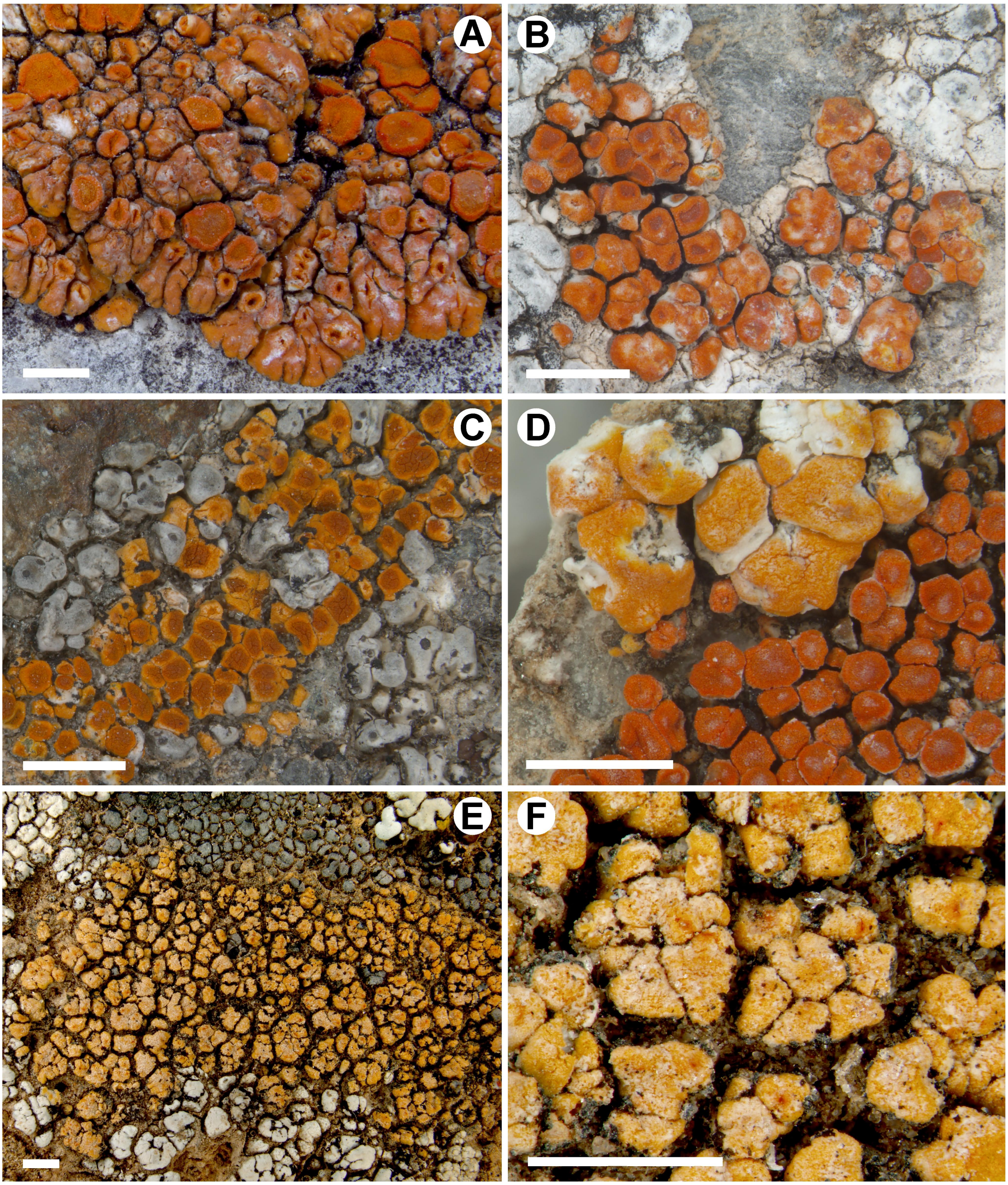

FIGURE 7. '*Caloplaca*' *anularis* group (A) and *Pachypeltis* (B–E). A, '*Caloplaca*' cf. *bohlinii* (Vondrák 18251) distinguished from '*C.*' *anularis* by orange thallus with more frequent apothecia; B, *Pachypeltis insularis* (Vondrák 10340); C, *Pachypeltis intrudens* (Vondrák 18059); D, *Pachypeltis* cf. *pachythallina* (large squamules) on *Calogaya* (Vondrák 12649); E, *Pachypeltis phoenicopta* (Vondrák 18695) having deep orange pycnidia contrasting with pale yellow colour of thallus; F, detail of areoles of *P. phoenicopta* (Vondrák 18695) showing patches of white pruina that gives the typical pale yellow colour to the thallus. All bars, 1 mm.

Pachypeltis insularis **(Poelt) Vondrák & I.V.Frolov, combinatio nova**
MycoBank: MB826776
Fig.: 7B.

Basionym: *Caloplaca insularis* Poelt in Planta 51: 300–301 (1958). Type:—[FRANCE]. Westalpen: Dept. H^{tes} Alpes, Montagne de Chaillol über dem Col du Lautaret, um [altitude] 2300 m, über schiefrigem Gestein [on schist, lichenicolous on calcicolous *Aspicilia*] 8. 1957, *Georges Clauzade & Josef Poelt* (holotype M; currently not available).

Taxonomy: The type specimen was not seen, but we studied a topotype collected and identified by J. Poelt and deposited in GZU: "Südosthänge des Grand Area, NNW of Briancon, altitude 2300 m, on limestone, lichenicolous on *Aspicilia*, 11 July 1970". The topotype morphology and the description (Poelt 1958), both clearly indicate that *Caloplaca insularis* belongs to *Pachypeltis*: thallus squamulose forming tight spots on host thalli, apothecial disc brown and rough, apothecial margin thick, medulla and part of the cortex at base of squamules amyloid (I+ blue). The topotype and a few other specimens from the Alps (deposited in GZU) are almost identical with specimens from the Altai-Sayan region, but the latter tend to form larger and thicker spots on the host thalli.

Geographic note: New to Greece from Mt Olympus (specimen Frolov 1671), see Table 1 for details.

4 localities at altitudes 1750–2900 m, in arid alpine habitats, but a single record from humid alpine site. Substrate: limestone, lichenicolous on *Aspicilia*.

Pachypeltis intrudens (= *Caloplaca infestans*), Fig. 7C: 3 localities at altitudes 1530–2900 m, in arid alpine class. Substrate: siliceous rocks or limestone; lichenicolous on various lichen crusts.

Caloplaca infestans was described by Magnusson (1944) from Mongolia (syntype L3406 in S!) and *Caloplaca intrudens* (= *Pachypeltis intrudens*) was described by Magnusson (1940) from Gansu, China (Syntype L2604 in S!). Magnusson distinguished *Caloplaca infestans* from *Caloplaca intrudens* by smaller apothecia, less lax paraphyses and larger ascospores with broader septa. Our measurements in the specimen Vondrák 18059 revealed large differences in ascospore sizes and thickness of septa among three measured apothecia: **(1)** ascospores (14–)14.8(–15) × (8–)8.1(–8.5) µm, septum 4.5–6 µm; **(2)** (13–)14.4(–17) × (7–)7.4(–8) µm, septum 3–5 µm; **(3)** (12.5–)14.2(–15.5) × (6–)7.5(–8) µm, septum 4–5 µm. Spore characters observed in our specimen overlap with values characterizing both Magnusson's species: ascospores 12–13 × 5.5–6.5 µm with septa 3–3.5 µm in *C. intrudens* and 13–15 × 8.5 µm with septa 4–5 µm in *C. infestans*. Type specimens of both species are lichenicolous on epilithic crustose lichens without differences in external appearance. The names are considered synonyms here, and the epithet *intrudens* has priority.

Pachypeltis pachythallina **(Poelt & Hinteregger) Vondrák, combinatio nova**
MycoBank: MB826777
Figs: 7D, 8.

Basionym: *Caloplaca pachythallina* Poelt & Hinteregger in Bibliotheca lichenologica 50: 169–170 (1993). Type:—CHINA. Xinjiang, Karakorum, Siang-Tal (right side of valley below glacier K2), alt. 4180 m, 36°03'N, 76°28'E, on noth-exposed granite rock with loess dust in crevices, collected by W. Bernhard Dickoré, 28 September 1986 (holotype GZU!).

Taxonomy: Described by Poelt & Hinteregger (1993) from a single but fertile fragment of lichen. Morphologically the type specimen resembles the lichenicolous *P. insularis* or *P. invadens*. The species was not considered lichenicolous by the original authors, but the thallus of the type is in contact with *Glypholecia scabra* and *Lecidea tessellata* var. *caesia*. The original authors noted that obviously lichenicolous sterile squamules in adjacent sites may belong to the same species. Our specimen from Altai (Vondrák 12649) matches the type in distinct cortex (c. 20–40 µm) extended to bases of squamules, in very thick medulla and in brown-red pycnidia (typical for *Pachypeltis*) and in size of conidia, c. 4–5 × 1.5–2 µm.

Recorded from two localities at altitudes 1600–3050 m (specimens Vondrák 12649, 12706) in arid alpine sites. Substrate: limestone, lichenicolous on *Calogaya biatorina* subsp. *asiatica* and *Gyalolechia lenae*. Both the type of *Caloplaca pachythallina* and our own specimens definitely belong in *Pachypeltis*, but we are not certain that the two are conspecific, and here we refer to our specimens as *Pachypeltis* cf. *pachyhthallina* (Table 1, Fig. 8); further study of material from Karakorum is desirable.

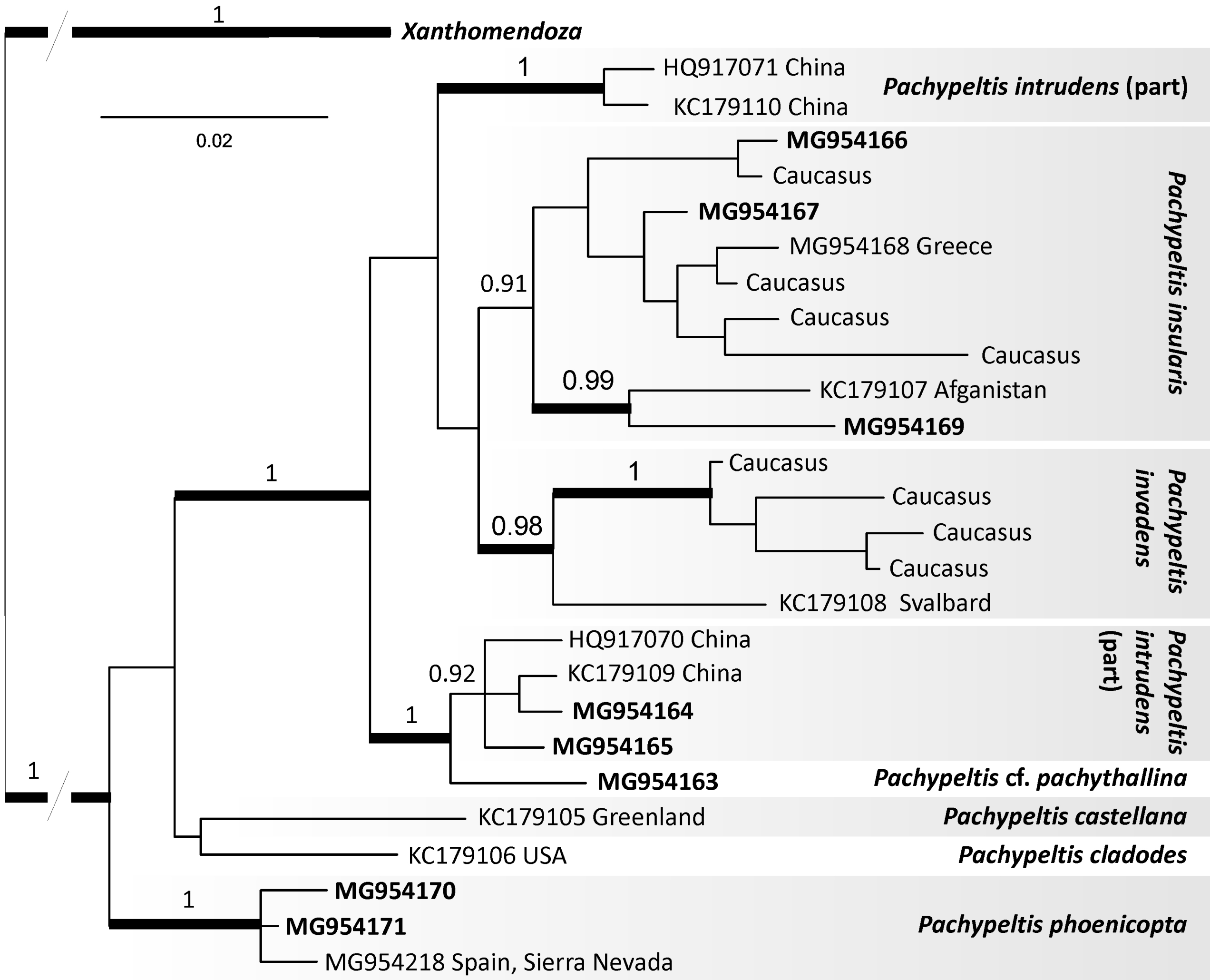

FIGURE 8. Bayesian phylogenetic reconstruction in *Pachypeltis* using the ITS DNA locus. Sequences from the Altai-Sayan region are in bold.

Pachypeltis phoenicopta **(Poelt & Hinteregger) Vondrák, combinatio nova**
MycoBank: MB826778
Figs: 7E–F, 8.

Basionym: *Caloplaca phoenicopta* Poelt & Hinteregger in Bibliotheca lichenologica 50: 175–176 (1993). Type:—NEPAL. Langtang area, S-exposed slopes N above Thangsep (Thogsep), ±3200 m, rocks in pastures and scrubs with *Caragana sukinensis*, on quartzite, associated with *Lecanora* [=*Caloplaca*] *demissa* and *Caloplaca saxicola* var. *chameleon* [=*Calogaya* sp.], collected by Josef Poelt, 2 September 1986 (holotype GZU!).

Taxonomy: Originally described as a lichenicolous lichen confined to *Caloplaca demissa* with a diagnostic contrast between pale ochraceous thallus and brown red apothecia (Poelt & Hinteregger 1993). Morphology and ecology of our specimens from Altai-Sayan region match the type specimen, but the pool of hosts differs and includes numerous lichen genera (see below). *Lecidella* sp. and *Rinodina* sp., belonging to the pool of hosts, would suggest identification of our specimens as *Caloplaca lecidellae* or *C. rinodinae* which were also described by Poelt & Hinteregger (1993) as host specific lichenicolous lichens from Himalaya. Based on our appraisals, both latter species do not have a specific "*Pachypeltis* appearence", but the type of *C. lecidellae* probably belongs to *Xanthocarpia* and the type of *C. rinodinae* resembles *C. sororicida*.

Geographic note: Also occurring in Sierra Nevada, Spain (specimen Vondrák 18191), see Table 1 for details.

3 localities at altitudes 1400–2500 m, in arid alpine habitats. Substrate: sun-lit siliceous rocks usually below overhangs, lichenicolous on *Aspicilia* sp., *Calogaya biatorina*, *Lecidella* sp., *Lobothallia* sp., *Rhizocarpon* cf. *disporum* and *Rinodina* sp.

Parvoplaca

Single arctic-alpine species recorded in the region. Thallus is crustose and inconspicuous, without vegetative diaspores; apothecia are abundant. Literature: Arup *et al.* (2013, 2015).

Parvoplaca tiroliensis: 16 localities at altitudes 1760–3140 m, mostly in humid alpine habitats. Substrate: bryophytes, plant debris, twigs of alpine shrubs, avoiding habitats with acidic bedrock.

Polycauliona

Single species recorded in the region. Thallus is very small fruticose, forming vegetative diaspores (blastidia/soredia); apothecia are rare. It has broad, bipolar distribution. Literature: Arup *et al.* (2013), Lindblom & Søchting (2008).
Polycauliona candelaria: 7 localities at altitudes 290–1400 m, in humid and rarely arid non-alpine classes. Substrate: bark on trunks and twigs of *Betula*, *Larix*, *Populus*, *Salix* and *Sorbus*.

Pyrenodesmia

Genus with highest species richness recorded in the region, 22 species were recorded. Thallus is crustose, varying from endolithic to thick epilithic with short marginal lobes. Colour of thallus and apothecia is in shades of grey and brown, anthraquinone pigmentation is always absent. Vegetative diaspores are present in five species; apothecia are produced by all species, but are less frequent in sorediate/blastidiate species. The genus is confined to inorganic substrates with strong preference for calcareous rocks. Only 11 species are listed here (5 of them left in '*Caloplaca*'); other species are either undescribed or taxonomically problematic (Frolov, in preparation). Literature: Muggia *et al.* (2008), Arup *et al.* (2013), Frolov *et al.* (2016), Wetmore (1994), Wunder (1974).

Pyrenodesmia chalybaea: 4 localities at altitudes 550–920 m, in arid non-alpine class. Substrate: limestone.

Pyrenodesmia concreticola: In a single locality at altitude 250 m, in arid non-alpine class (specimen Frolov 1561). Substrate: loess.

Pyrenodesmia erodens: 7 localities at altitudes 470–2900 m, in arid alpine and non-alpine classes. Substrate: limestone, marble.

Pyrenodesmia micromontana: 2 localities at altitudes 2170–2900 m, in arid and humid alpine habitats. Substrate: limestone, schist.

Pyrenodesmia microstepposa: 5 localities at altitudes 410–2350 m, mostly in arid non-alpine habitats; single record in arid alpine class. Substrate: calcareous sandstone, concrete, lime-enriched silicate, limestone.

Pyrenodesmia variabilis: 8 localities at altitudes 400–1750 m, in all ecological classes except for humid alpine (due to scarcity of calcareous substrates). Substrate: limestone, marble.

'*Caloplaca*' *helygeoides*: 9 localities at altitudes 420–2660 m, in humid alpine and non-alpine habitats. Substrate: siliceous stones mainly in or near water. The name *C. diphyodes* (Nyl.) Jatta has been commonly used for this mostly arcto-alpine species. However, *C. diphyodes* sensu Nylander (1872) is a distinct unrelated species known only from non-alpine localities in the Massif Central, France (Frolov, in preparation).

'*Caloplaca*' *molariformis*: In a single locality at altitude 2050 m, in arid alpine class (specimen Vondrák 10224). Substrate: soft calcareous outcrop.

'*Caloplaca*' *pratensis*: 6 localities at altitudes 400–2050 m, in arid alpine and non-alpine classes. Substrate: lime-rich silicate, limestone. First published records from Eurasia; described from North America (Wetmore 2009).

'*Caloplaca*' aff. *tianshanensis*: In a single locality at altitude 1700 m, in arid non-alpine class (specimen Vondrák 10457). Substrate: limestone. Phylogenetically the specimen is very close to *C. tianshanensis*, but it is morphologically distinct.

'*Caloplaca*' *transcaspica*: 4 localities at altitudes 600–2900 m, in arid alpine and non-alpine classes. Substrate: lime-rich silicate, limestone.

Rufoplaca (Figs 9, 10)

5 epilithic species recorded in the region. Thallus crustose, but sometimes strongly reduced and concentrated below apothecia. Vegetative diaspores are absent; apothecia are usually numerous. The genus is characterised by thin ascospores with thin septa. (*Xanthocarpia* usually has ascospores with thin septa and a similar shape, but larger.) Anthraquinones are only in apothecia and Sedifolia-grey pigment is often present in the thallus. Almost confined to siliceous rocks, but rarely on dust impregnated wood. Two of five species in the region are lichenicolous. Taxonomy is not resolved. Our provisional taxonomic concept is based on the ITS DNA phylogeny and phenotypic differences recognized among specimens in different ITS lineages. Literature: Arup *et al.* (2013).

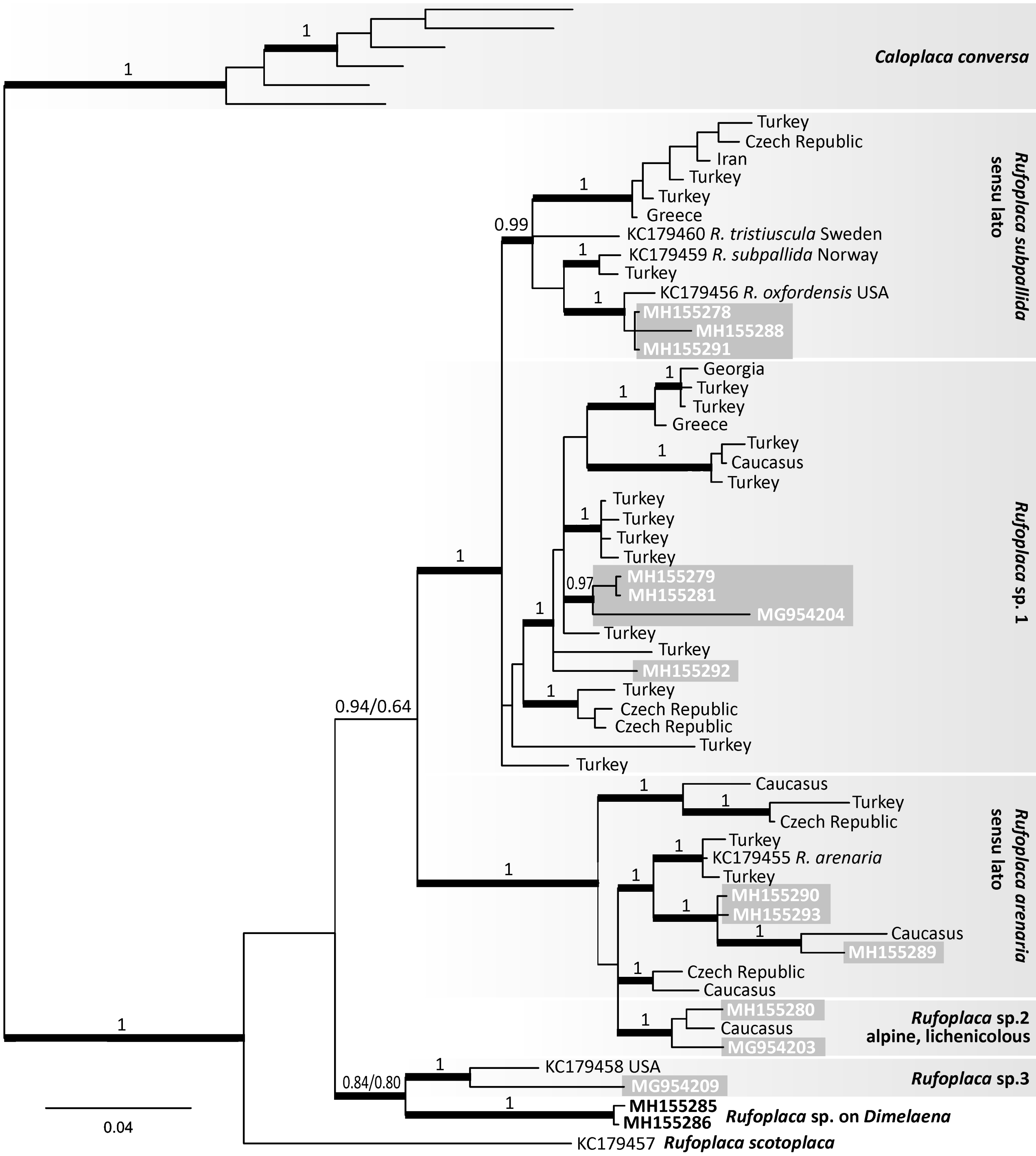

FIGURE 9. Bayesian phylogenetic reconstruction of *Rufoplaca* using the ITS DNA locus. Sequences from the Altai-Sayan region are in grey squares.

Rufoplaca arenaria sensu lato (Fig. 10A): Two specimens recorded at altitude 1120 m in humid non-alpine habitat. Substrate: granite (Vondrák 18693) and also mineralized wood of *Larix* (Vondrák 18371). Characterised by red apothecial margin being C+ purple (dissolved C solution required, see Vondrák & Wirth 2013). Chemical nature of the positive C-reaction is unclear; C+ substances (gyrophoric acid known from *Rufoplaca* or chlorinated anthraquinones) are absent from apothecia in the specimen Vondrák 18371 (analysed by LC-MS). Thallus is inconspicuous. Identity of *Rufoplaca arenaria* sensu stricto is unclear. The name *R. arenaria* is adopted from the concept by Arup *et al.* (2013).

Rufoplaca subpallida sensu lato (Fig. 10B): 6 localities at altitudes 400–1700 m in humid non-alpine or alpine sites. Substrate: siliceous rocks, rarely mineralized wood (Vondrák 19241). Characterised by thin but distinct brownish-grey epilithic thallus; traces of greyish thalline exciple are often observed; apothecia are typically with yellow-orange margin and brown-orange discs. ITS DNA sequences from Altai-Sayan region are closely related to sequences of American *R. oxfordensis* (Fig. 9). Here we regard *R. oxfordensis* as contained within *R. subpallida* sensu lato.

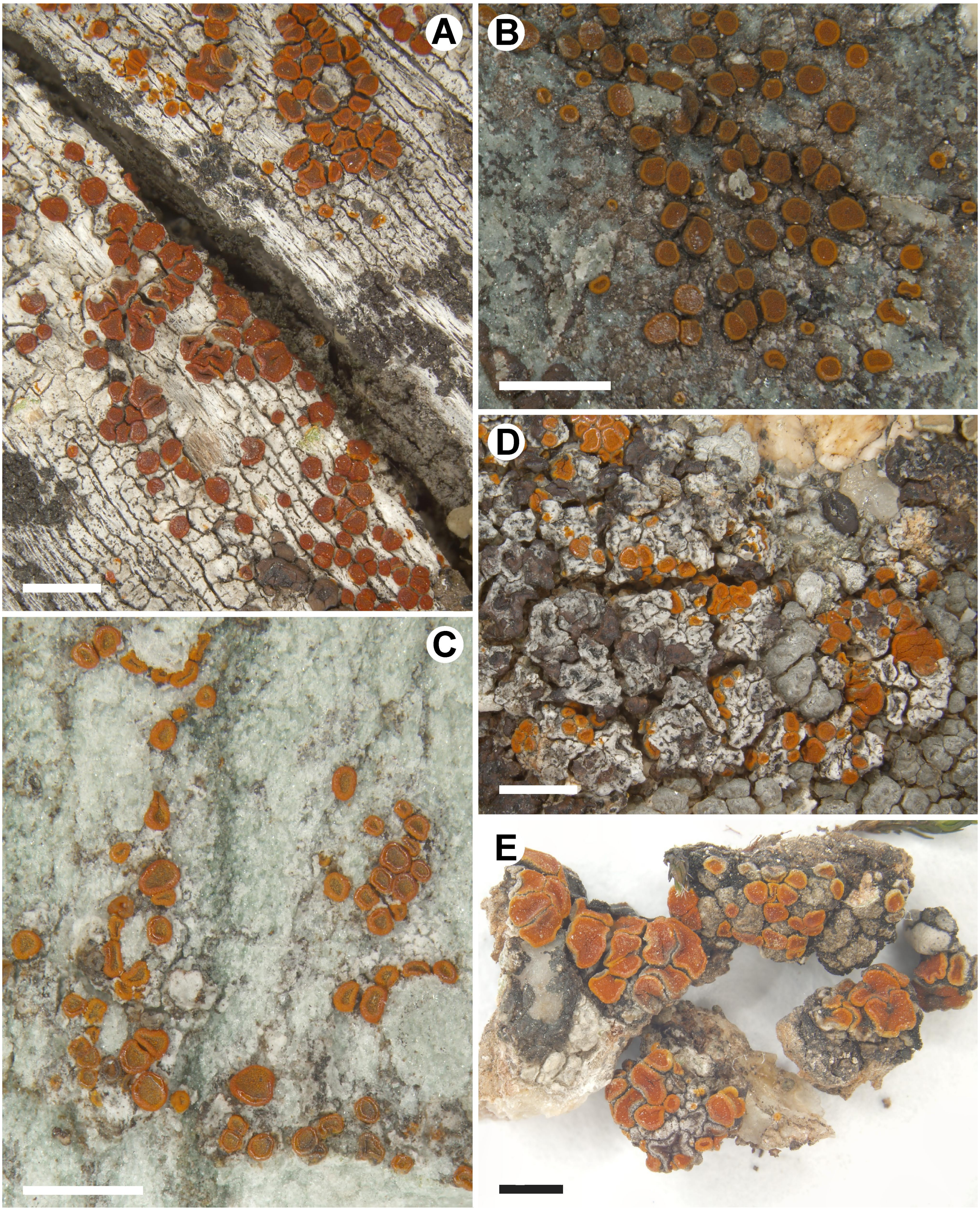

FIGURE 10. *Rufoplaca* (A–E). A, *Rufoplaca arenaria* sensu lato (Vondrák 18371; on mineralized wood) with apothecia more red than orange; B, *Rufoplaca subpallida* sensu lato (Vondrák 9929) with a distinct grey thallus, brown-orange apothecial disc and pale orange apothecial margin; C, *Rufoplaca* sp. 1 (Vondrák 12663) with slight olive tinge in apothecial discs; D, *Rufoplaca* sp. 2 (Vondrák 9924) forming bleached necrosis on *Acarospora* sp.; E, *Rufoplaca* sp. 3 (Davydov 17245) with large apothecia and a yellow outer part of the true exciple. All bars, 1 mm.

Rufoplaca sp. 1 (Fig. 10C): 19 localities at altitudes 390–3000 m in all ecological categories. Substrate: various types of siliceous rocks, rarely on wood (not recorded on wood in the region). Most common *Rufoplaca* in the region. It is similar to *R. arenaria* sensu lato, but is characterised by orange apothecial disc and margin being C- (caution: C+ purple in concentrated hypochlorite solution, see Vondrák & Wirth 2013). In some specimens, mostly from upper altitudes, apothecial disc has yellow to olive tinged anthraquinone pruina (Fig. 10C). *Rufoplaca* sp. 1 as proposed in Fig. 9 does not form a homogeneous group in the ITS tree and probably includes more than one species.

Rufoplaca sp. 2 (Fig. 10D): In two localities at altitudes 2050–3000 m, in humid alpine sites (specimens Vondrák 9924, 18681). Substrate: gneiss, lichenicolous on lichen crusts (*Aspicilia*, *Acarospora*, *Miriquidica deusta*). Characterised by indistinct thallus, sometimes forming colourless necroses on host lichen; apothecia are orange, small and crowded, forming small spots on host thallus, sometimes containing Sedifolia-grey pigment in outer apothecial margin.

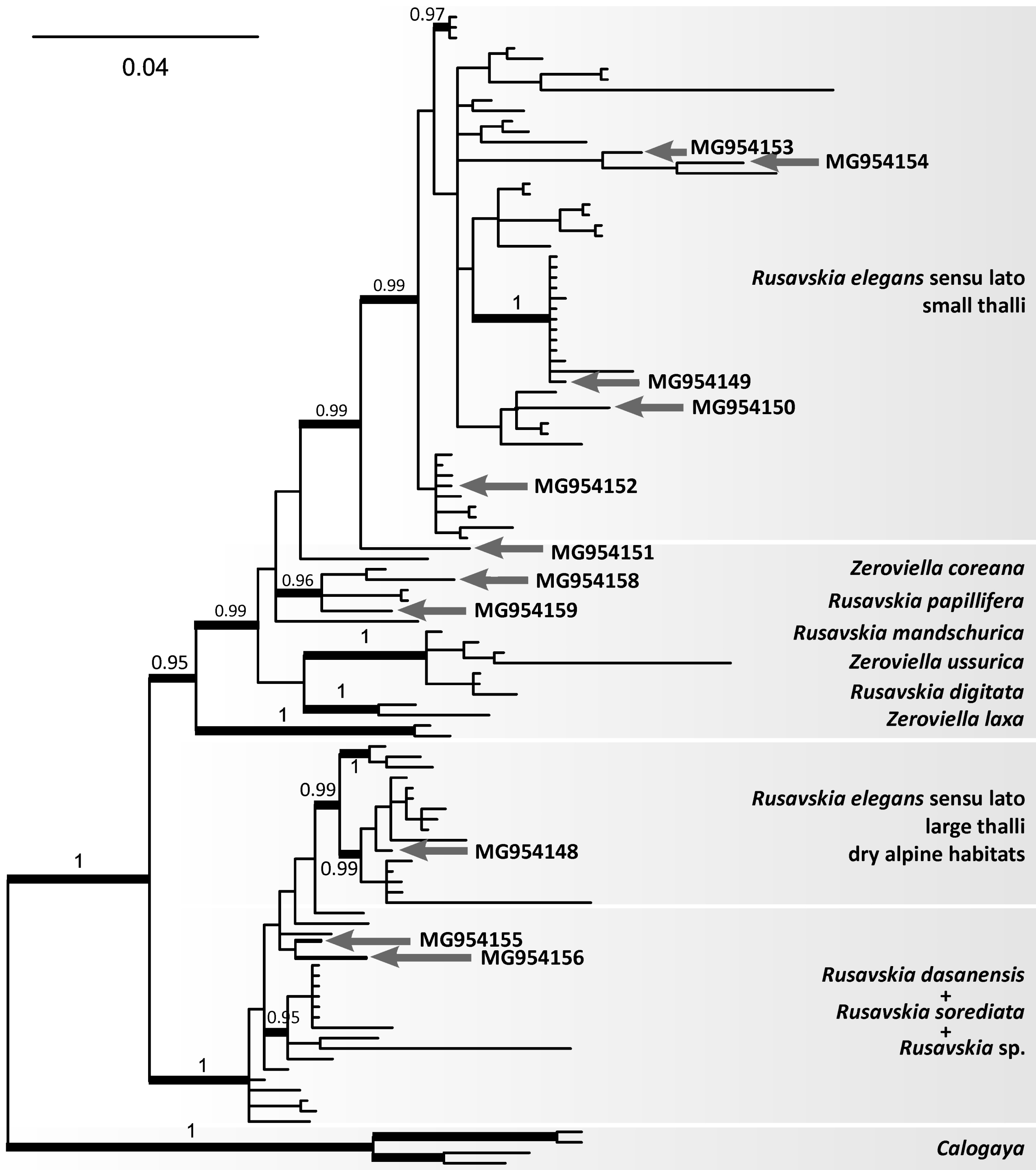

FIGURE 11. Bayesian phylogenetic reconstruction of *Rusavskia* using the ITS DNA locus. Sequences from the Altai-Sayan region are indicated by arrows.

Rufoplaca sp. 3 (Fig. 10E): Single specimen recorded at altitude 500 m, in humid non-alpine habitat (Davydov 17245). Substrate: quartzite, lichenicolous on a crustose lichen (perhaps *Aspicilia*). The specimen contains only fragments of thalli. Characterised by the yellow rim of true exciple that smoothly turns to grey thalline exciple (the yellow rim in apothecial margin is rare in *Rufoplaca*). Thallus is thin, pale, without obvious pigmentation. Apothecia are orange, reaching 1 mm diam. (Usual size of mature apothecia in *Rufoplaca* is about 0.5 mm diam.)

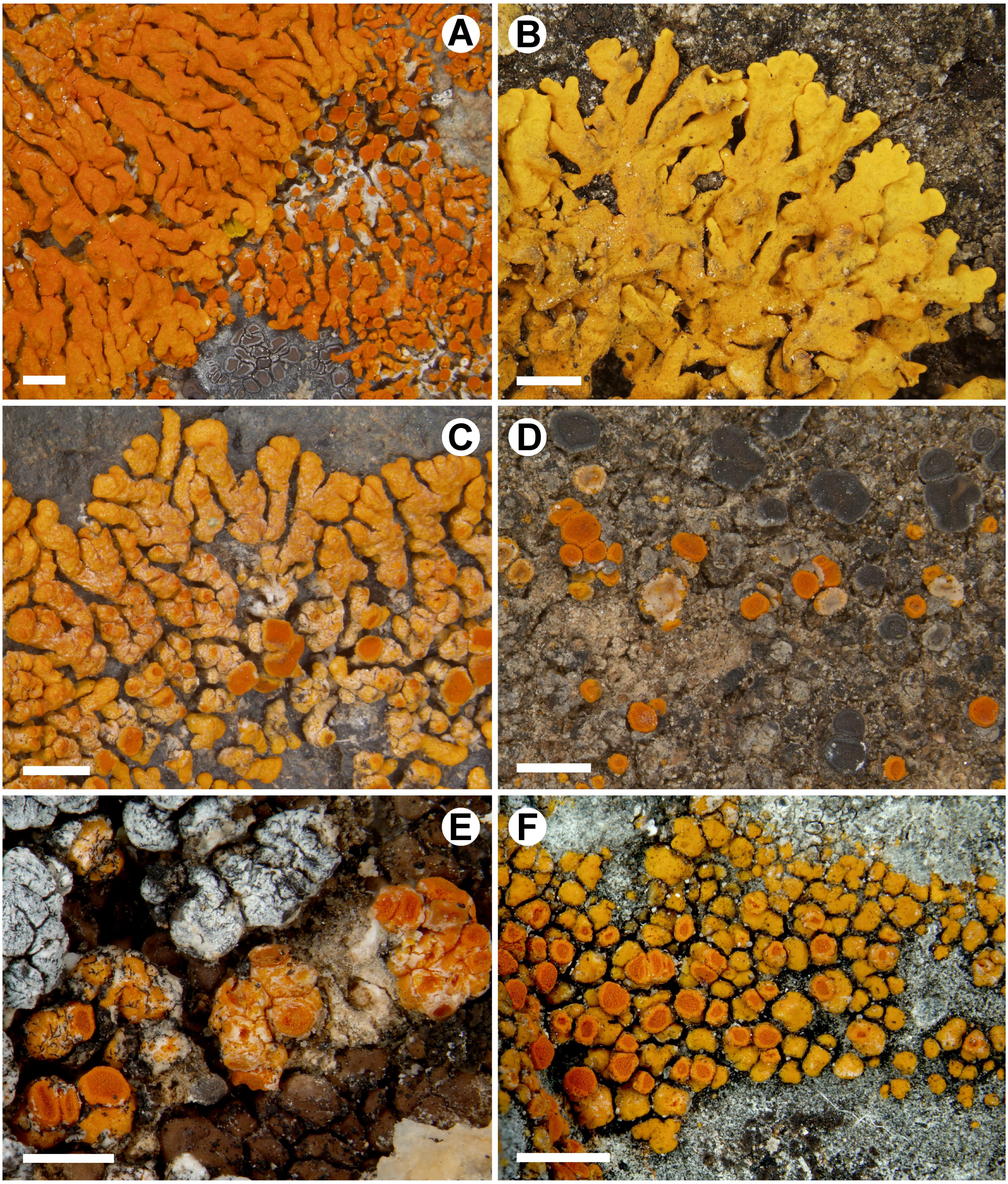

FIGURE 12. *Rusavskia* (A–C) and variability in *Variospora sororicida* (D–E). A, *Rusavskia elegans* (Vondrák 18104), large and small morphotypes included, both are distinct in ITS; B, *Rusavskia* sp. 1 (Vondrák 18102) with *Xanthoria*-like flat lobes; C, *Rusavskia* sp. 2 (Vondrák 18161) with appressed lobes to substrate; D, *Variospora sororicida* (Vondrák 18071) with strongly reduced thallus on *Pyrenodesmia*; E, *V. sororicida* (Vondrák 18680) with few distinct areoles, on *Pyrenodesmia*; F, *V. sororicida* with numerous areoles, not obviously lichenicolous (Vondrák 18223). All bars, 1 mm.

Rusavskia (including *Zeroviella*) (Figs 11, 12A–C)
At least 5 species recorded in the region occurring on various inorganic substrates, but rarely also on bark, organic soil or bryophytes. Thallus is foliose or crustose with marginal lobes. Vegetative dispores are present in two species (blastidia in *R. sorediata*, lobules in *R. dasanensis*). Apothecia are known in all species, but sometimes not developed. Taxonomy is not settled and our species delimitation is provisional, reflecting ITS tree topology (Fig. 11) and phenotypic variability. Literature: Arup *et al.* (2013), Khodosovtsev *et al.* (2004), Kondratyuk & Kärnefelt (2003), Kondratyuk *et al.* (2013b, 2015).

Rusavskia dasanensis: 24 localities at altitudes 250–3140 m in arid (rarely humid) habitats. Substrate: sun-lit limestone and siliceous rocks. Hardly distinguished from *R. papillifera*, *R. digitata*, and *R. domogledensis*. ITS sequences from Altai specimens are close to available *R. dasanensisis* sequences. The Mediterranean *R. papillifera* belongs to a different clade. Lichens from Altai-Sayan region are morphologically variable; with flat thallus outgrowths (characteristic for *R. papillifera*) or with coralloid isidia (*R. dasanensis*). Identities of European *R. digitata*, and *R. domogledensis* are not clear.

Rusavskia elegans sensu lato (specimens with small thalli), Fig. 12A right: 34 localities at altitudes 220–2900 m in all ecological categories. Substrate: limestone and siliceous rocks.

Rusavskia elegans sensu lato (specimens with large thalli), Fig. 12A left: 4 localities at altitudes 1400–1800 m mostly in arid or humid alpine habitats. Substrate: siliceous or calcareous rocks exposed to sun.

Rusavskia sorediata: 4 localities at altitudes 220–1800 m in all ecological categories except arid alpine. Substrate: base-rich siliceous and calcareous rocks.

Rusavskia sp. 1, Fig. 12B: 8 localities at altitudes 250–1400 m in arid, rarely humid, non-alpine habitats. Substrate: limestone. Easily distinguished from other *Rusavskia* in the region by flat yellow lobes resembling species of *Xanthoria*. It is common on limestone in forest-steppe zone at northern slopes of Altai.

Rusavskia sp. 2, Fig. 12C: Single specimen recorded at altitude 1570 m in arid non-alpine habitat (Vondrák 18161). Substrate: siliceous rock (schist). In the ITS tree (Fig. 11), its sequence MG954150 groups with *R. elegans*, but it is distinguished by lobes tightly appressed to substrate, and cortex and algal layer modified into algal and fungal stacks (see Vondrák & Kubásek 2013).

Seirophora
Two species recorded in the region. Thallus is yellow-orange with anthraquinones or grey, fruticose to foliose. Vegetative diaspores are present as tiny thallus outgrowths. Apothecia are known in all species, but often not developed. Apothecia and pycnidia are always with anthraquinones. Literature: Arup *et al.* (2013), Frödén & Lassen (2004), Frödén & Litterski (2005), Søchting & Frödén (2002).

Seirophora contortuplicata: 11 localities at altitudes 700–2900 m mostly in arid alpine habitats. Substrate: calcareous soil and weathered limestone, often in rock fissures.

Seirophora lacunosa: Recorded in single site of lowland desert at altitude 220 m (specimens Davydov 16921, 16922, 17449 & Yakovchenko). Substrate: red loam with gypsum in desert community with *Anabasis salsa*, *Atriplex cana,* and *Suaeda physophora*.

***Shackletonia* sensu lato** (Fig. 13)
Only one species was recorded in the territory. Thallus is grey, reduced to tiny fragments surrounding apothecia; lichenicolous on epilithic lichens. Vegetative diaspores are absent. Apothecia are with anthraquinones (chlorinated anthraquinones present). Literature (not including Northern Hemisphere lichens): Arup *et al.* (2013), Garrido-Benavent *et al.* (2016).

'*Caloplaca*' *epithallina*: 20 localities at altitudes 300–2900 m in all ecological categories. Substrate: siliceous rocks; lichenicolous on various crusts (rarely on foliose lichens): *Aspicilia* sp., *Buellia* sp., *Dimelaena oreina*, *Lecanora muralis*, *Montanelia* sp., *Pleopsidium flavum*, *Protoparmelia* sp., *Rhizocarpon* sp., *Rhizoplaca peltata* and *R.* cf. *subdiscrepans*. Anthraquinone content in apothecia (specimen 18287): 7-Cl-emodin (major), parietin (subdominant), emodin (minor), 7-Cl-emodinal (minor), 2 unknown compounds (minor).

Squamulea (including *Huriella*)
Only one species recorded in the region. Thallus is crustose, formed of small squamules. Vegetative diaspores are absent; apothecia are present. It is confined to inorganic substrates. Literature: Arup *et al.* (2013), Kondratyuk *et al.* (2017).

Squamulea sp., Fig. 5D: Only one specimen recorded at altitude 660 m (Vondrák 18682), in arid non-alpine habitat. Substrate: vertical side of sandstone outcrop in steppe. Specimen is morphologically similar to the European *Squamulea subsoluta* (ITS similarity 91–92%), but its ITS sequence is closer to two species from the Far East: *Huriella loekesiana* (95–96% similarity) and *Squamulea* sp. (KJ133481, 98% similarity).

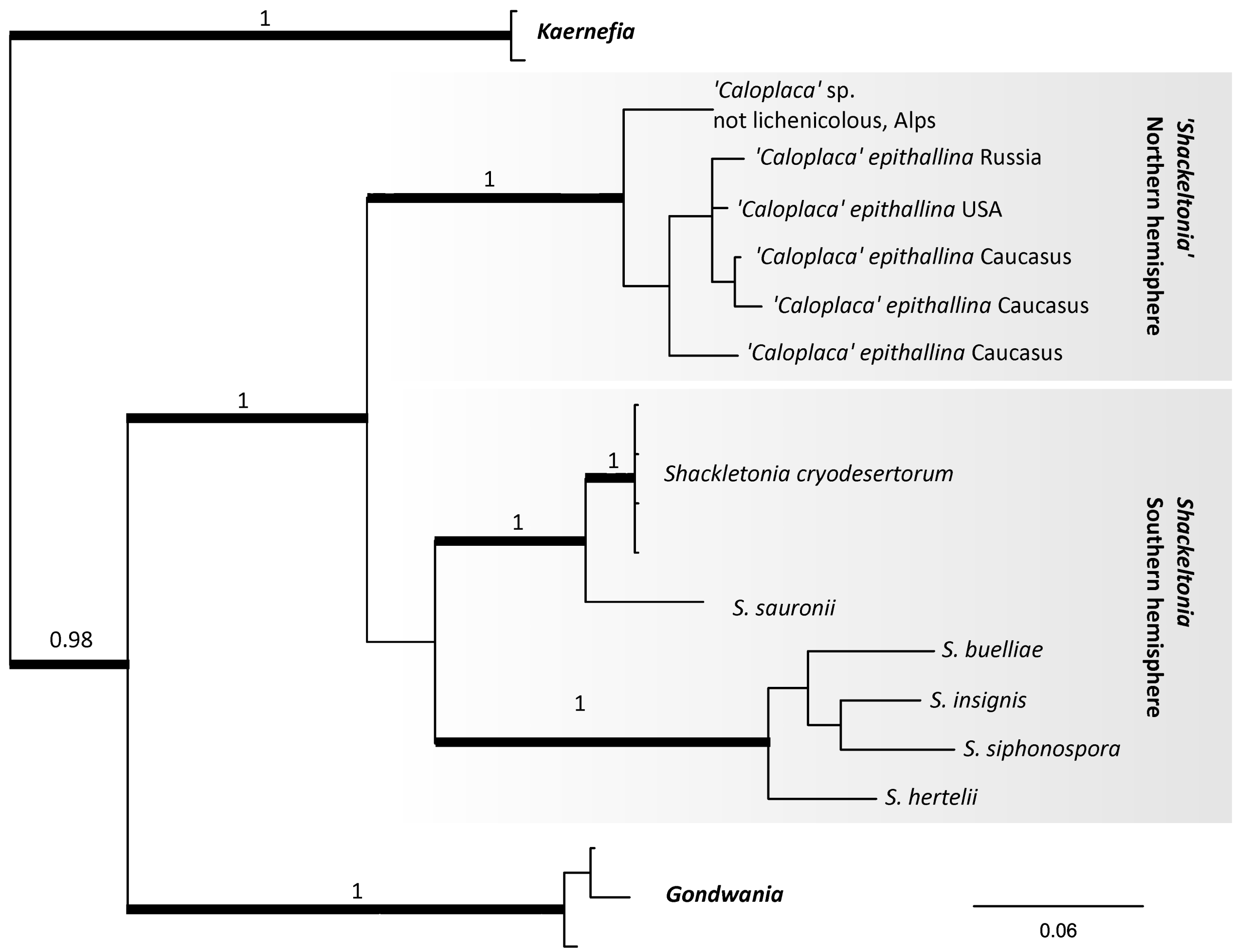

FIGURE 13. Bayesian phylogenetic reconstruction employing the ITS DNA to show the relationship of *Shackeltonia* and '*Caloplaca*' *epithallina*.

Variospora (Figs 12D–F, 14)

Two species recorded in the region. Thallus is crustose, areolate, or reduced in lichenicolous specimens. Vegetative diaspores are absent; apothecia are present. Both species are confined to inorganic substrates. Some species have ascospores with a specific shape, with thickened wall or without broadened septa, but species in the region have common polarilocular ascospores. Literature: Arup *et al.* (2013), Vondrák *et al.* (2017).

Variospora dolomiticola: 14 localities at altitudes 410–2900 m, mostly in arid alpine and non-alpine habitats. Substrate: calcareous rocks; not lichenicolous.

***Variospora sororicida* (M. Steiner & Poelt) Vondrák, combinatio nova**

MycoBank: MB826779

Figs: 12D–F, 14.

Basionym: *Caloplaca sororicida* M. Steiner & Poelt, in Poelt & Hinteregger, Bibliotheca Lichenologica 50: 201–204 (1993). Type:—AFGHANISTAN. Province Kabul, hill c. 3 km east of airport, 34°35'N, 69°17'E, alt. 1850 m, epilithic on outcrop of calcareous schist in south-facing steppe slope, *Maxmilian Steiner*, 30 April 1970 (in Lichenotheca Afghanica 63, holotype GZU!).

Taxonomy: Described as an adelphoparasitic species, lichenicolous strictly on *Caloplaca* (*Pyrenodesmia*) *transcaspica*, forming tiny areoles bearing clusters of crowded apothecia (Poelt & Hinteregger 1993). A broader ecological and morphological concept is proposed here. (1) The species is not restricted to a single host but occurs on various lichen crusts (see below); (2) development of thallus is variable: almost absent (Fig. 12D), surrounding crowded apothecia (Fig. 12E) or formed of numerous tiny areoles similar to *V. dolomiticola* but smaller; latter morphotypes are not strictly lichenicolous (Fig. 12F). In our experience, *V. sororicida* is broadly distributed in dry continental regions of Eurasia, e.g. in dry habitats of Turkey, Caucasus, southern Ural. Most sequences of *V. sororicida* form a supported clade in the ITS tree (Fig. 14), but few sequences are unresolved in the tree together with some sequences of *V. dolomiticola*, perhaps a result of ancestral polymorphy. *Variospora dolomiticola* and *V. sororicida* are morphologically distinct, mainly in size. *V. dolomiticola* has larger thalli, thalline areoles and apothecia. *Variospora epierodens* described from the Alps (Roux *et al.* 2017; Hafellner & Muggia 2006 sub *Caloplaca* sp.) is also lichenicolous on *Pyrenodesmia*, but has well developed areolate thallus resembling more *V. dolomiticola*.

13 localities at altitudes 400–2350 m in arid alpine and non-alpine habitats. Substrate: calcareous rocks; typically lichenicolous on *Pyrenodesmia* (e.g. *P. helygeoides*, *P. erodens*), but also on *Rinodina* and *Aspicilia*.

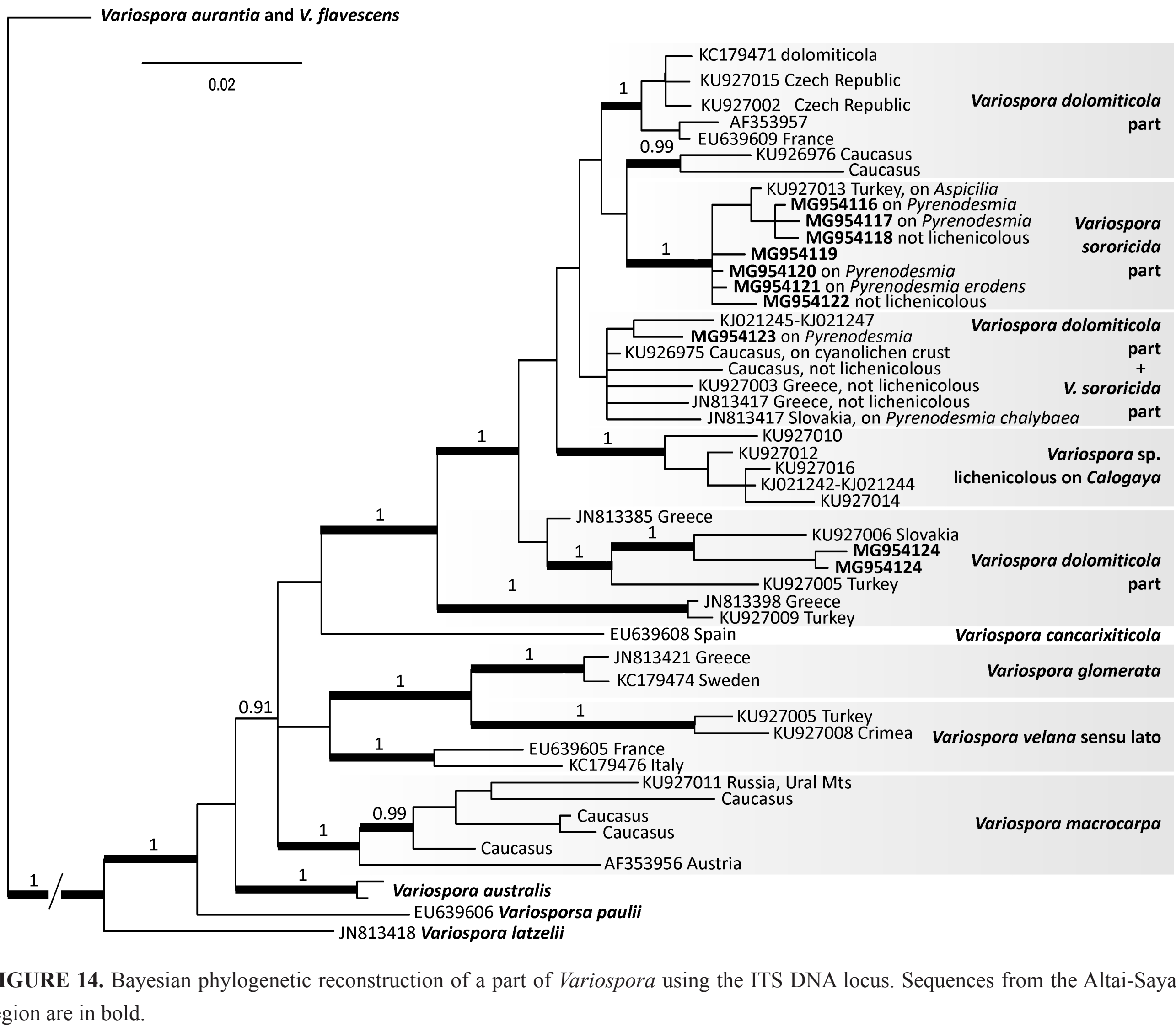

FIGURE 14. Bayesian phylogenetic reconstruction of a part of *Variospora* using the ITS DNA locus. Sequences from the Altai-Sayan region are in bold.

Xanthocarpia

Five species recorded in the region. Thallus is yellow (rarely pale grey, without anthraquinones), areolate (in *X. interfulgens*), but usually strongly reduced, endolithic or restricted to thalline apothecial margin. Vegetative diaspores are only present in the sorediate *X. tominii*. Apothecia are present. All species are confined to inorganic substrates, strongly preferring calcareous rocks or concrete (rarely on mineralized wood). Species richness is high in dry continental Asia and Mediterranean Europe; degree of overlap in species composition between those regions is not clear yet. The genus is characterised by narrowly ellipsoid ascospores with thin septa (three septate ascospores in the European

X. ochracea). *Rufoplaca* has similar, but generally shorter and even narrower ascospores and preferrs more acidic siliceous rocks. Literature: Arup *et al.* (2013), Vondrák *et al.* (2011, 2017).

Xanthocarpia crenulatella sensu lato: 12 localities at altitudes 250–1640 m, mostly in arid and humid non-alpine habitats. Substrate: calcareous rocks (sandstone, limestone) and concrete.

Xanthocarpia ferrarii sensu lato: 17 localities at altitudes 400–2350 m, mostly in arid alpine and non-alpine habitats. Substrate: calcareous rocks (sandstone, limestone, schist) and concrete.

Xanthocarpia interfulgens: 15 localities at altitudes 250–2900 m, mostly in arid alpine and non-alpine habitats. Substrate: calcareous rocks (sandstone, limestone).

Xanthocarpia cf. *marmorata*, Fig. 16C: 11 localities at altitudes 400–1750 m, mostly in arid alpine and non-alpine habitats. Substrate: limestone. Distinct from the Mediterranean *X. marmorata* in larger apothecia and in ITS sequences.

Xanthocarpia tominii: 7 localities at altitudes 250–2900 m in all ecological categories but humid non-alpine. On organic or inorganic substrate: sandstone, schist (often calcareous), plant debris, hard soil.

Xanthomendoza (including *Golubkovia*; see Arup *et al.* 2013 for other included genera)
Three species recorded in the region. Two of them (*X. fulva*, *X. ulophyllodes*) belong to the *Xanthoria ulophyllodes* group (sensu Søchting *et al.* 2002), having tiny, thin foliose thalli with upper and lower cortex and indistinct medulla; both species produce vegetative diaspores (soredia, blastidia); apothecia are uncommon. The third species, *X. trachyphylla*, placed in the monotypic genus *Golubkovia* sensu Kondratyuk (2014b), is characterised by a thick crust with long marginal lobes and with thick upper cortex and medulla; lower cortex is absent; vegetative diaspores are absent; apothecia are present on mature thalli. Literature: Arup *et al.* (2013), Lindblom (2004), Lindblom & Søchting (2008), Søchting *et al.* (2002).

Xanthomendoza fulva: 3 localities at altitudes 250–430 m in humid non-alpine nabitats. Substrate: bark of *Populus tremula* and *Sorbus sibirica*.

Xanthomendoza trachyphylla (= *Caloplaca hedinii*): 3 localities at altitudes 2050–2900 m in arid alpine habitats. Substrate: siliceous rocks (then thalli without pruina; Fig. 5E) or calcareous rocks (thalli with pruina in older parts; Fig. 5F). Type of *Calpolaca hedinii* (L2652 in S) described by Magnusson (1940) is from Central Asia and represents typical *Xanthomendoza trachyphylla* (synonymisation already made by Khodosovtsev *et al.* 2004).

Xanthomendoza ulophyllodes: 26 localities at altitudes 300–1730 m, in all ecological categories, but rare in alpine habitats. Substrate: variable, (1) calcareous or siliceous rocks, often on schist and sandstone, (2) bark of e.g. *Larix*, *Pinus*, *Populus*, *Salix*, (3) twigs of shrubs, e.g. *Caragana* and (4) over epigeic mosses. Similar species, *X. fallax* (mainly epilithic) and *X. huculica* (mainly epiphytic) were not recorded. ITS sequences of epilithic, corticolous and muscicolous specimens from Altai grouped with *X. ulophyllodes*.

Xanthoria (sensu Arup *et al.* 2013)
One species recorded in the region. All species have large foliose thalli; vegetative diaspores are absent; apothecia are present. Literature: Arup *et al.* (2013), Lindblom (1997; including other present-day Xanthorioid genera).

Xanthoria parietina: 2 localities at altitudes 200 and 210 m. Both localities humid non-alpine and both at city of Barnaul. Substrate: bark of *Populus*. It is marginally distributed in the region and possibly restricted to lowlands north of Altai.

'*Caloplaca*' *anularis* group (Fig. 15)
Four species recorded in the region. Thallus is crustose, with marginal lobes; vegetative diaspores are absent; apothecia are sometimes present. Thallus typically very thick, with thick medulla (often several hundred μm) and thick cortex (tens of μm); algal and fungal stacks (sensu Vondrák & Kubásek 2013) sometimes present. Thallus and apothecia are with non-chlorinated anthraquinones. The group forms a genus-level clade in *Xanthorioideae*, perhaps with sister relationship to *Amundsenia* (Fig. 2). It is broadly distributed and diverse in arid and alpine regions of Asia and probably absent from Arctic regions. Literature: Clauzade & Poelt (1972), Lee *et al.* (2018), Poelt & Hafellner (1980), Vondrák & Mayrhofer (2013).

'Caloplaca' anularis: 6 localities at altitudes 1500–2900 m, mostly in arid alpine habitats. Substrate: limestone rocks.

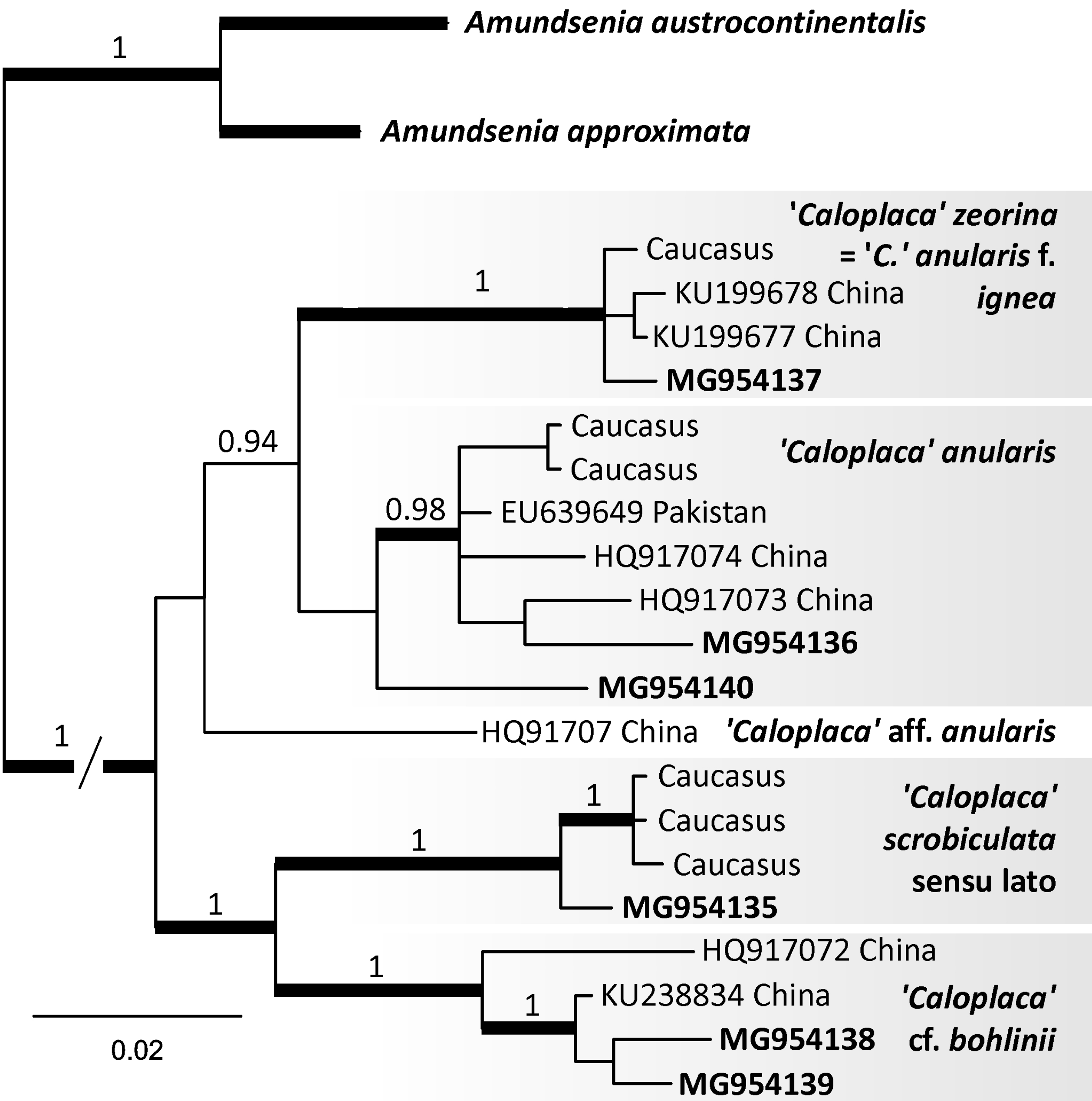

FIGURE 15. Bayesian phylogenetic reconstruction of the '*Caloplaca*' *anularis* group using the ITS DNA locus. Sequences from the Altai-Sayan region are in bold.

'Caloplaca' cf. *bohlinii*, Fig. 7A: 3 localities at altitudes 900–1750 m, in arid alpine and non-alpine habitats. Substrate: limestone rocks. It is distinguished from *C. anularis* by smaller, compact, orange thalli with shorter and broader marginal lobes. This species never forms ring-shaped fragments of thalli (sensu Vondrák & Mayrhofer 2013). It is also similar to *C. scrobiculata*, but thallus is less robust with fewer white pruinose spots, algal and fungal stacks are less distinct and marginal lobes less reduced. The little known *C. bohlinii* was described by Magnusson (1940) from Central Asia. Its type specimen (L2622 in S!) has intermediate phenotype between *C. anularis* and *C.* cf. *bohlinii* and the identity of our material is thus uncertain.

'Caloplaca' scrobiculata: single specimen recorded at altitude 3000 m in arid alpine locality in Altai (Vondrák 9933). Substrate: limestone boulder.

'Caloplaca' zeorina (= *Caloplaca anularis* f. *ignea*): single record at altitude 2900 m in arid alpine locality in Altai (specimen Vondrák 9928). This taxon is phenotypically distinct from *C. anularis* and both taxa are also separated in the ITS tree (Fig. 15). Its status at species level therefore seems to be correct.

'*Caloplaca*' *ahtii*

Our single ITS sequence (MG954161) is placed in subfamily *Xanthorioideae*, but stands outside any known clade (Fig. 2); it may belong in a genus of its own. The single species forms thin grey crusts with tiny crater-like soralia containing the pigment Sedifolia-grey. This pigment is also frequently present in outer apothecial margin, giving a grey tinge. Apothecia are yellow to orange, containing anthraquinones of chemosyndrome A. It is a typical boreal species common in taiga forests, usually epiphytic. Literature: Søchting (1994).

Caloplaca ahtii: 13 localities at altitudes 350–1490 m, mostly in humid, non-alpine habitats (forests). Substrate: bark of *Populus* and *Salix*, rarely on other trees, also on wood and exceptionally on dust-impregnated rock (Vondrák 10404).

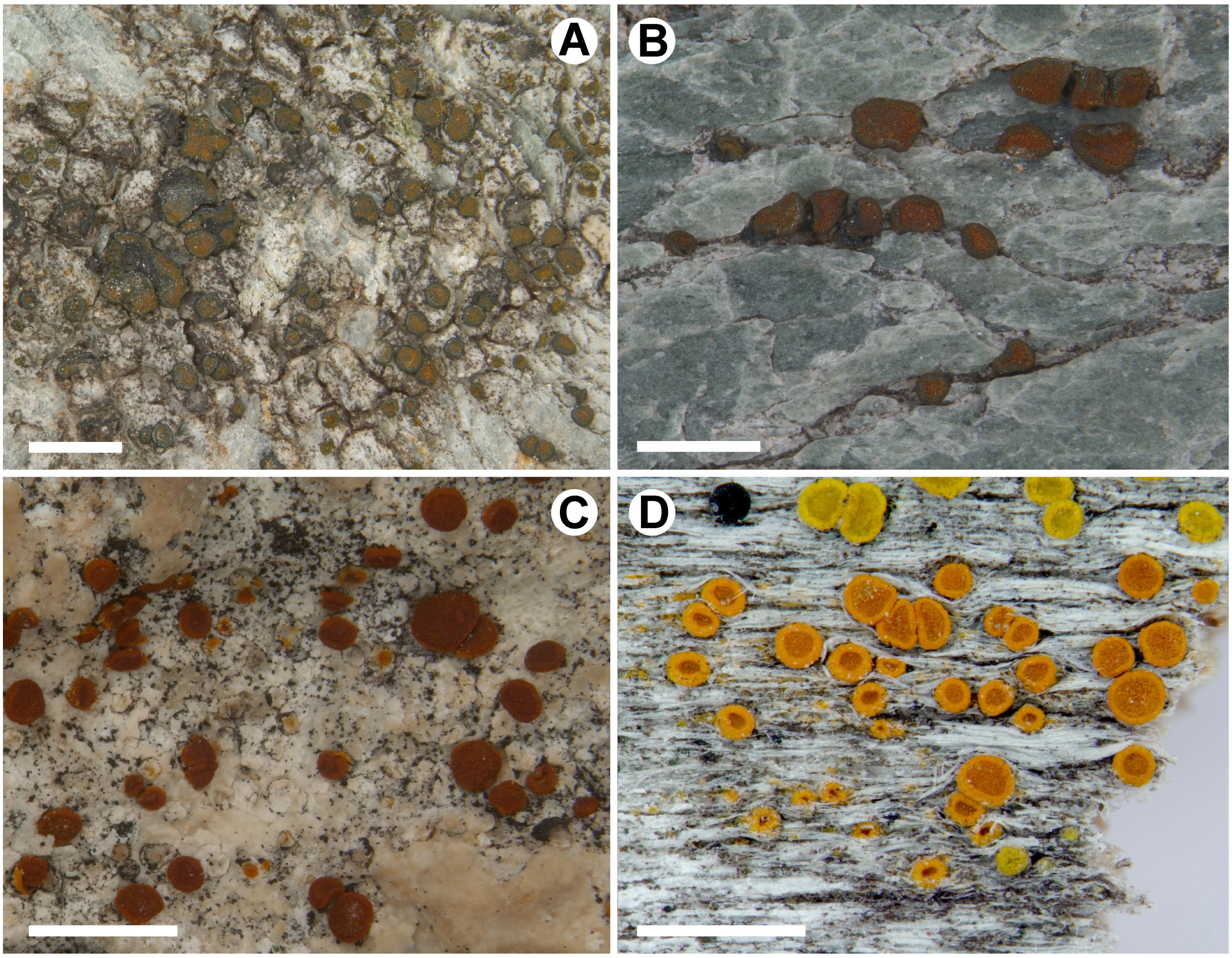

FIGURE 16. '*Caloplaca*' *exsecuta* (A, B), *Xanthocarpia* (C) and an unknown '*Caloplaca*' (D). A, '*Caloplaca*' *exsecuta* (Vondrák 11110) with yellow-orange discs; B, '*C.*' *exsecuta* (Vondrák 11105) with ferrugineous red discs; C, *Xanthocarpia* sp. (Vondrák 18686) resembling the Mediterranean *X. marmorata*; D, unknown '*Caloplaca*' with unresolved ITS position within *Xanthorioidae* (Vondrák 18687). All bars, 1 mm.

'*Caloplaca*' *exsecuta* group (Figs 16A, B)

Three species recorded in the region. All species are crustose, with thin or indistinct thallus. Vegetative diaspores are present in *Caloplaca sorocarpa* which is usually without apothecia. Apothecia are usually numerous in other species, containing anthraquinones in disc or in both disc and margin. Non-chlorinated anthraquinones predominate: parietin (major), emodin (minor) and traces of emodinal, emodic acid, parietinic acid and fallacinal (analysed specimens of *C. exsecuta*: Vondrák 1105, Tønsberg 46194). 7-Cl-emodin was not seen in UV, but was identified by mass spectrometry in Tønsberg 46194. Thallus and usually apothecial margin has Cinereorufa-green (sometimes only detected in prothallus); anthraquinones are absent from thallus. The group includes boreal-montane to arctic-alpine species. The three species listed below form a monophyletic group in ITS tree together with *Caloplaca tornoenesis* and *C. nivalis* (newly sequenced specimens in Table 1). The group is defined here and no relevant literature is available.

'Caloplaca' borealis: 2 localities at altitudes 1120–1530 m in humid non-alpine and subalpine habitats. Substrate: bark of *Abies sibirica*.

'Caloplaca' exsecuta: 2 localities at altitudes 1260–2180 m in humid alpine habitats. Substrate: base-rich siliceous rocks. Colour of disc variable: yellow-orange in specimen Vondrák 11110 (Fig. 16A), but ferrugineous red in specimen Vondrák 11105 (Fig. 16B).

'Caloplaca' sorocarpa: only recorded from a single locality at altitude 1580 m in humid subalpine habitat (specimen Vondrák 12695; Western Sayan). Substrate: twig of *Grossularia* shrub. Probably more frequent in the region.

'*Caloplaca*' *conversa/conglomerata* group

One species recorded in this group which is placed the subfamily *Caloplacoideae* and close to a group of species called "section *Coccinodiscus*" sensu Poelt & Kalb (1985), see Fig. 2. The group, as currently known to us, is morphologicaly characterised by presence of large amounts of Sedifolia-grey in all parts of the thallus and in apothecial margin. Anthraquinones are often confined to apothecial disc, but in some specimens, anthraquinones are replaced by Sedifolia-grey in discs. All specimens are epilithic. High diversity was observed in the Mediterranean basin (Vondrák, unpublished). Specimens of *Rufoplaca* with grey apothecial margin are sometimes very similar to some *C. conversa* morphotypes, but ascospores are broad and with thick septa in *Caloplaca conversa/conglomerata* group, but narrow with thin septa in *Rufoplaca*. The group involves at least two morphospecies, *C. conversa* (thin areolate crusts) and *C. conglomerata* (= *C. peludella*) with thicker squamulose thallus, but more phylogenetic lineages are involved. Literature: Nimis (2016), Redchenko *et al.* (2012; ITS sequence of the type of *C. conversa*).

'Caloplaca' conversa sensu lato: 7 localities at altitudes 400–1230 m, mostly in arid non-alpine habitats. Substrate: base-rich siliceous or calcareous rocks (limestone, schist, gneiss), usually on xerothermic outcrops in forest-steppe zone.

'*Caloplaca*' *haematites/aractina* group

One species recorded in the region. Thallus is crustose, white-grey, without anthraquinones, epilithic, thinly areolate. Vegetative diaspores are absent. Apothecia are orange-red, with non-chlorinated anthraquinones. It is related to *Pyrenodesmia*, but forms a genus-level group with European and Mediterranean *C. aractina* and *C. haematites* (Frolov, in preparation). Literature: Magnusson (1940).

'Caloplaca' bicolor (= *Caloplaca kansuensis*): 3 localities at altitudes 2050–2900 m in arid alpine habitats. Substrate: hard limestone and soft calcareous rock (schist). In other regions also known from siliceous rocks. No differences were found between types of *Caloplaca bicolor* (L2616 in S) and *C. kansuensis* (L2603 in S). The two names were given to two different taxa by Magnusson (1940), but we consider them synonymous.

'*Caloplaca*' *raesaenenii*

The species resembles some species of *Athallia*. It has indistinct thallus; vegetative diaspores are absent; apothecia are with non-chlorinated anthraquinones, small, initially immersed in substrate. It does not group with any known genus in ITS tree. Literature: Vondrák *et al.* (2012a).

'Caloplaca' raesaenenii: 12 localities at altitudes 250–2230 m, mostly in arid non-alpine habitats. Substrate: epiphytic, on bark and twigs of trees and shrubs, on plant debris and bryophytes (in steppes on calcareous substrate).

'*Caloplaca*' *xerica* group

Five species recorded in the region, but all are rare in the region. Thallus is crustose, white to dark grey, with Sedifolia-grey pigment; vegetative diaspores are present in *C. soralifera* (soredia, blastidia), *C. teicholyta* (blastidia) and *C. xerica* (blastidia, isidia); apothecia are present in all species, but rare in *C. teicholyta*; chlorinated and non-chlorinated anthraquinones are present. The group is confined to inorganic substrates, usually on mineral-rich siliceous rocks. It is related to *Pyrenodesmia* but merits its own genus (Frolov, unpublished). Literature: Arup *et al.* (2013), Vondrák *et al.* (2012b).

'Caloplaca' atroflava: Only one specimen recorded at altitude 430 m in humid non-alpine habitat (Frolov 1519). Substrate: gneiss rock.

'Caloplaca' percrocata: Only one specimen recorded at altitude 2300 m in humid alpine habitat (Davydov 12295). Substrate: rock.

'Caloplaca' soralifera: 4 localities at altitudes 410–480 m in humid and arid non-alpine habitats. Substrate: base-rich siliceous or calcareous rock.

'Caloplaca' teicholyta: 2 localities at altitudes 410–1900 m in arid alpine and non-alpine habitats. Substrate: limestone.

'Caloplaca' xerica: Two specimens recorded in one locality at altitude 1480 m in humid non-alpine habitat (Frolov 175, Vondrák 10292). Substrate: gneiss rock, below overhang. This species is known to be xerophilous in Europe, but was not recorded from arid habitats in the Altai-Sayan region.

***Coccinodiscus* group**
Single species recorded in the region. Thallus is crustose, of a few brown areoles, or entirely reduced; lichenicolous. Vegetative diaspores are absent. Anthraquinone content in apothecial disc is unknown. *Coccinodiscus* group was introduced by Poelt & Kalb (1985) as a section of *Caloplaca* including *C. congrediens*, *C. grimmiae*, *C. phaeothamnos*. Close relationship of all three species is supported by the ITS sequence data (Vondrák, in preparation).

'*Caloplaca*' *grimmiae*: 6 localities at altitudes 600–2200 m in all ecological classes, except for humid non-alpine. Substrate: siliceous rocks, lichenicolous on *Candelariella vitellina*.

unknown '*Caloplaca*' sp. (Fig. 16D)
It resembles some species of *Athallia*. Thallus is endophloedal and concentrated below apothecia. Vegetative diaspores are absent. Apothecia contain non-chlorinated anthraquinones. Identity of the species is unclear; it has no close relatives in the ITS tree. Single specimen was recorded at altitude 1120 m in sparse *Larix* forest on hard wood of *Larix* stump (Vondrák 18687).

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APPENDIX 1. List of localities involved in the study. Environmental classes follow the classification in the Methods. Coordinates are in the WGS84 system.

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
1	1	China, Xinjiang	Kabinsky range, at 8 km SE settlement Purbe (Bai-Kaba), N macroslope of the Dzhata Mt, left bank of the Purbe River. Picea obovata - Larix sibirica forest, 1.8.2005	1400–600	48.684167, 86.800556
1	2	China, Xinjiang	Kabinsky range, vicinity of Terekty, left bank of the Terekty River, Picea obovata forest on the rivers bank, rocks, 15.7.2007	1100	48.469167, 86.687222
1	3	China, Xinjiang	Mongol'sky Altai range, right bank of Irtysh River at 15 km NE settlement Kektogoy, opposite of St. Bear Mt, Picea obovata forest, wet rocks, 7.8.2005	1400	47.298333, 89.971111
1	4	China, Xinjiang	Mongol'sky Altai range, west part of Korumtytau Mts., valley of right tributary of Yelt-gol from the mountain situated in 5 km of the Barytumsuktau peak to the mouth, 24.7.2007	1550	47.937500, 88.967500
1	5	China, Xinjiang	N part of Kungeitytau Mts. at 18 km NNE Altai City, the valley of Kelan River, Picea obovata forest, stones near the water, 5.8.2005	1580	47.994444, 88.261667
1	6	Kazakhstan, Vostochno-Kazakhstansky Region	Katon-Karagai district, Sarymsakty range, to W from Uralkungei Mt (2818 m) at 5 km to S from Katon-Karagai settlement, Pinus sibirica - Larix sibirica forest, 8.9.2013	1750	49.120000, 85.563056
1	7	Kazakhstan, Vostochno-Kazakhstansky Region	Katon-Karagai district, Tarbagatai (Altai), 2 km S of Uryl', mixed forest (Picea obovata, Abies sibirica, Pinus sibirica, Larix sibirica, Betula pendula, Sorbus sibirica) along the Soldatsky Klyuch creek, 8.9.2011	1259	49.213889, 86.331111
1	8	Russia, Altai Territory	Altaisky district, The left bank of Katun' River at 0.5 km NE of the community of Nizhnaya Ustyuba, mixed forest (Pinus, Betula); foot of crest, stones, 3.10.2002	300–350	51.883333, 85.766667
1	9	Russia, Altai Territory	Altaisky district, The left bank of Katun' River at 1 km S of the community of Aya, E bank of Pionerskoye (Puchina) lake, 3.10.2002	350	51.900000, 85.833333
1	10	Russia, Altai Territory	Altaisky district, The left bank of Katun' River at 1 km SE of the community of Aya, spoiled Betula forest near the road, 3.10.2002	300	53.900000, 85.833333
1	11	Russia, Altai Territory	Altaisky district, The left bank of Katun' River at 3 km downstream from the community of Nizhnaya Ustyuba, Salix alba and Populus nigrum, 3.10.2002	290	51.883333, 85.783333
1	12	Russia, Altai Territory	Charyshsky district, Bashchelaksky range, left bank of Sosnovaia River at 2 km S of the community of Ozyorki, slopes of Tolstaya Mt. Betula forest near the stream, 19.5.1996	300–400	51.533333, 83.366667
1	13	Russia, Altai Territory	Charyshsky district, Korgonsky range, Charysh River's velley near the junction of Tulata creek, E and NE slopes of Mokhnataia Mt, 8.7.1994	600–800	51.416667, 83.416667

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
1	14	Russia, Altai Territory	Charyshsky district, Korgonsky range, left bank of Charysh River near the community of Charyshskoie, on N exposition cliff above the water, 2.7.1994	400	51.366667, 83.583333
1	15	Russia, Altai Territory	Charyshsky district, Korgonsky range, left bank of Gorelyi Korgon River at 8 km upstream from it's mouth, S slope, stones fields, 27.6.1998	1400	51.033333, 83.766667
1	16	Russia, Altai Territory	Tret'jakovsky district, Tigireksky range, near headwaters of Glubokaya River, Mayachnaya Mt, 9.6.1999	800–900	50.950000, 82.700000
1	17	Russia, Altai Territory	Charyshsky district, Korgonsky range, right bank of Gorelyi Korgon River at 9 km upstream from it's mouth, N slopes, Pinus sibirica - Abies sibirica forest, 29.7.1998	1400	51.016667, 83.750000
1	18	Russia, Altai Territory	Charyshsky district, Korgonsky range, right bank of Sentelek River near it's headwaters, Abies sibirica - Betula pendela forest, 22.5.1996	1200–1700	51.033333, 83.633333
1	19	Russia, Altai Territory	Charyshsky district, Tigireksky range, at 8.6 km S from the community of Tigirek, taiga forest (Pinus sibirica, Betula tortuosa, Abies sibirica), 24.6.2014	1450	51.070833, 82.996389
1	20	Russia, Altai Territory	Charyshsky district, Tigireksky range, Malyi Tigirek River valley near it's mid section, in forest belt, 12.7.1996	700–1500	51.083333, 83.066667
1	21	Russia, Altai Territory	Gorno-Altaysk, Sarasa, small marble cliff in W-slope above river Sarasa, c. 5 km S of village, in forest-steppe zone, 4.7.2012	500	51.832287, 85.342595
1	22	Russia, Altai Territory	Kosikhinsky district, at the North coast of the Krasilovo Lake, Pinus sylvestris - Betula pendula forest, 3.7.2007	250	53.183333, 84.350000
1	23	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, 1,5 S form the settlement of Tigirek, Chainaya Mt, Abies sibirica - Populus tremula oldgrown forest, 8.3.2009	637	51.124694, 83.029306
1	24	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, N macroslope, 1 km S from the Tgirek community, siliceous rock outcrops, single Larix sibirica and Betula pendula, 24.7.2015	500	51.104444, 83.042222
1	25	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, the community of Chineta, Populus trees near Inia River, 1995	380	51.333333, 83.050000
1	26	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, Tigirek strict reserve, at ca. 5 km NNW from the community of Tigirek, Larix sibirica forest wirh Rosa sp., 6.5.2007	925	51.189611, 82.991556
1	27	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, Tigirek strict reserve, Khankharinsky cluster left bank of the Dragunsky kluch creek, at 5.8 km NW from the community of Tigirek, 19.6.2014	870	51.185833, 82.975000

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
1	28	Russia, Altai Territory	Pervomaisky district, rightbank side of the Ob' River at 5 km to S from the Povalikha settlement, Pinus sylvestris forest, 5.2013	140	53.463611, 83.787222
1	29	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, at 3.3 km NW from the community of Tigirek, forest-steppe, Logovo gieny Cave, 13.7.2016	710	51.166125, 82.995566
1	30	Russia, Altai Territory	Soloneshensky district, Bashchelaksky range, right bank of Chernovoi Anui River at 2–3 km upstream of the community of Telezhikha, S slope, mixed forest, 3.9.1994	600	51.516667, 84.266667
1	31	Russia, Altai Territory	Soloneshensky district, Bashchelaksky range, velley of Shinok River, downtream of the waterfall, 29.6.2003	1035	51.354500, 84.567667
1	32	Russia, Altai Territory	Zalesovsky district, Salair range, headwaters of the Berd' River at 20 km NE from the Kordon settlement, Abies sibirica - Populus tremula toll grasses forest, 29.5.2012	430	54.416667, 85.116667
1	33	Russia, Altai Territory	Zalesovsky district, Salair range, Upstream of the Berd' River at 20 km NE from the Kordon settlement, Abies sibirica - Populus tremula toll grasses forest, 12.5.2014	430	54.416667, 85.116667
1	34	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, headwaters of Irkutka River at 12 km S of Tigirek settlement and 2.5 km NW of Razrabotnaya Mt, Taiga forest (Abies sibirica, Pinus sibirica), 23.7.2012	1300–1400	51.039722, 82.997222
1	35	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, left bank of Belaya River opposite the mouth of the Irkutka River, Abies sibirica dominanted tall gresses forest (Chern'), 14.7.2005	700–800	50.955556, 82.974167
1	36	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, right bank of Strizhanka River, stream flowing from the unnamed Mt (elev. 1043 m), Abies sibirica dominanted mountain taiga relict forest (Chern'), 15.7.2005	720–800	50.933056, 82.956944
1	37	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, left bank of Glukharikha River 0.5 km up of junction with Belaya River, valley Salix forest, 12.8.2003	560	51.001667, 82.761667
1	38	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, near the headwaters of the Irkutka River, Abies sibirica dominanted mountain taiga relict forest (Chern'), 18.7.2005	885	51.020556, 82.968333
1	39	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, right bank of the Belaya River, 7 km upstream to the mouth of the Berlozhia river, Abies sibirica - tall grasses forest, 7.7.2006	717	50.959444, 83.049722
1	40	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, the junction of the rivers Malaya Belaya and Belaya, Salix forest, 21.7.1997	470	51.083333, 82.650000

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
1	41	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, the velley of the Irkutka River near it's mouth (Belaya River), Abies sibirica and velley Salix forests, 14.7.2005	650	50.960556, 82.978056
1	42	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, western part of the range at 5 km S of the community of Andreevsky, near the mid section of the Zagornaya Amelikha River, Abies sibirica - Populus tremula mountain relict forest, 26.6.2003	986	51.056167, 82.852
1	43	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, western part, Abies sibirica - Betula pendula fern–all grasses forest, 12.7.2006	1000	51.113611, 83.016944
1	44	Russia, Kemerovo Region	Kemerovo, about 50 km NE of city, forest with Populus tremula, Betula and Abies sibirica, 16.6.2013	350	55.630278, 86.450000
1	45	Russia, Krasnoyarsk Territory	West Sayan Mts, Minusinsk, at road Minusinsk - Kizil, 3 km N of Buybinsky Pass, montane forest with Abies sibirica on granite, 20.6.2013	1310	52.883605, 93.254722
1	46	Russia, Krasnoyarsk Territory	West Sayan Mts, Minusinsk, Shushenskoe, 10 km SE of village Tanzibey, forest in valley of river Bolshoy Kebezh, with Abies, Salix, Prunus padus, and few old Populus laurifolia, 20.6.2013	440	53.083062, 93.094423
1	47	Russia, Republic of Altai	Chemal district, Ust-Sema, SW-exposed rocks in valley of river Katun, c. 2 km SE of village, volcanic scree and outcrops, 6.7.2012	400–600	51.625545, 85.778990
1	48	Russia, Republic of Altai	Chemal, diabase / limestone cliffs above right bank of river Katun, at settlement Elanda, 6.7.2012	500	51.289894, 86.054711
1	49	Russia, Republic of Altai	Chemal, schist outcrops in slope above right bank of river Katun, c. 4 km S of Chemal, 5.7.2012	420–1000	51.358257, 86.035797
1	50	Russia, Republic of Altai	Choya district, Karakoksha, mosaic of cultural forests and meadows, c. 10 km W of village, 14.7.2012	500	51.783479, 86.580965
1	51	Russia, Republic of Altai	Choya district, Karakoksha, settlement Uymen, peak 1686 m, c. 30 km S of Karakoksha, 14.7.2012	1600	51.610014, 86.833878
1	52	Russia, Republic of Altai	Kosh-Agach district, Kuray Steppe, c. 4 km W of Kuray, gneiss outcrops in valley of river Kyzyltash, 12.7.2012	1480	50.228984, 87.883775
1	53	Russia, Republic of Altai	Kosh-Agachsky district, Kuraisky range, right bank of Kuraika River at 5 km N of Kurai settlement, riverside Larix sibirica - Picea obovata forest, 15.7.2013	1670	50.266944, 87.951389
1	54	Russia, Republic of Altai	Onguday district, Tuekta, SW-exposed gneiss rocks in valley of river Tuekta, 9.7.2012	900	50.826536, 85.921831
1	55	Russia, Republic of Altai	Ongudaysky district, at 10 km E of Ust'-Kan at left bank of Yabagan River, marginal part of the fog, limestones, 30.6.2003	1057	50.933333, 84.900000
1	56	Russia, Republic of Altai	Ongudaysky district, Seminsky range, left bank of the Ursul river. Larix sibirica - Betula microphylla - Salix forest near the bank, 4.6.2005	1022	50.819722, 85.597222

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
1	57	Russia, Republic of Altai	Shebalino district, Topuchaya, gneiss rocks on SW-slope above river Sarlyk, c. 1 km NE of village, 7.7.2012	1200	51.140681, 85.599684
1	58	Russia, Republic of Altai	Shebalinsky district, Seminsky range, W part of Sarlyk Mt., middle section of right tributary of Sarlyk River, Eslope, rock outcrops in meadow steppe or Larix sibirica forest, 2.7.2016	1400	51.11000, 85.626667
1	59	Russia, Republic of Altai	Turochak district, Artibash, SW-exposed, gneiss rocks above right bank of river Biya, c. 5 km NW of village, 18.7.2012	450–700	51.814335, 87.202184
1	60	Russia, Republic of Altai	Turochak district, Kebezen, gneiss rocks above right bank of river Biya, NW of village, 17.7.2012	400–450	51.931402, 87.079041
1	61	Russia, Republic of Altai	Ulagan district, Balykcha, Koo, NE-exposed granite scree of large boulders, c. 7 km NW of village, 22.12.2012	500	51.137788, 87.835472
1	62	Russia, Republic of Altai	Ulagan district, volcanic scree on S-slope above river Chuya, c. 7 km E of settlement Yarbalik, 10.7.2012	1200	50.365627, 87.301737
1	63	Russia, Republic of Tyva	5 km NE of village Samagaltay, sun-exposed siliceous outcrops in forest-steppe with Larix, 27.6.2013	1400	50.628611, 95.068323
1	64	Russia, Republic of Tyva	Balgazin, 4 km SE of village Ilinka, meadows and forests (Picea obovata, Larix, Betula, Pinus sibirica) in valley of river Buren, 3.7.2013	870	51.063333, 95.544722
1	65	Russia, Republic of Tyva	Kizil, 8 km NW of village Balgazin, Pinus sylvestris forest on sand dunes, 26.6.2013	950	51.056660, 95.099444
1	66	Russia, Republic of Tyva	Shuurmak, 8 km S of village Kuran, Larix forest on siliceous bedrock, 26.6.2013	1160	50.720826, 95.304167
1	67	Russia, Republic of Tyva	West Sayan Mts, Ak-Dovurak, Ak-Sug, 2 km N of settlement Enge-Beldir, lit Larix forest on gravel terrace of river Kara-Sug, 8.7.2013	1490	51.618896, 90.076410
1	68	Russia, Republic of Tyva	West Sayan Mts, Ak-Dovurak, Alash, 2 km SE of village Ak-Sug, siliceous rocks in forest-steppe, in valley of river Ak-Sug, 8.7.2013	1120	51.400300, 90.444800
1	69	Russia, Republic of Tyva	West Sayan Mts, Turan, 2.5 km N of village Shivilig, sun-exposed mica-schist outcrop (steppe-spot) in frequently burned forest with Pinus sylvestris and Larix, 22.6.2013	1440	52.260284, 93.693056
1	70	Russia, Altai Territory	Barnaul, in city, Yubileinyi Park	210	53.368962, 83.720848
1	71	Russia, Altai Territory	Barnaul, South Siberian Botanical Garden	200	53.262782, 83.669458
2	72	China, Xinjiang	Burqin county, Yuzhny Altay range, South Altai range, south slope, valley of left tributary of Ak-Kaba in 5 km from the border with Kazakhstan and in 6 km to NEE of the peak 3030 m, degraded alpine meadows, gravely tundra, rocks, 17.7.2007	2300–2600	49.028056, 86.843889

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
2	73	China, Xinjiang	Kabinsky range, vicinity of settlement Purbe (Bai-Kaba), Dryas octopetala mountain tundra with alpine elements on W slope, rock outcropes, 1.8.2005	2400–2700	48.657778, 86.835000
2	74	China, Xinjiang	Mongol'sky Altai range, SE slope of mt. Keshtau (3511 m), gravely tundra, rocks, 31.7.2007	3136	46.755000, 90.837500
2	75	China, Xinjiang	Mongol'sky Altai range, upper reaches of Khara-Belchir-he, west slope of mt. Kara-Balchigtau (3215 m), Larix sibirica forest, 30.7.2007	2400	46.702222, 90.974722
2	76	China, Xinjiang	Mongol'sky Altai range, upper reaches of Khara-Belchir-he, west slope of mt. Kara-Balchigtau (3215 m), Larix sibirica forest, steppe slopes with Juniperus spp., rocks, 30.7.2007	2656	46.700000, 90.946944
2	77	China, Xinjiang	N part of Kungeitytau Mts. at 20 km NE Altai City, upper reaches of Kelan River, pastured alpine meadow, boulders, rocks, 5.8.2005	1970	48.000833, 88.341389
2	78	China, Xinjiang	Saur range, eastern part, northern slope, valley of left tributary of Tastykarasu in 70 km SE of Zimunai, polyherbal meadow steppes with Pentaphylloides fruticosa and Kobresia communities in depressions, 12.7.2007	2145	47.070556, 86.158889
2	79	China, Xinjiang	Saur range, Saur, S slope, valley of Karakyia in 5–7 km to the south of Karagaityninkezen'pass (2360 m), ca. 30–35 km NE of Hophose (Kobuk), degraded Larix forest, 11.7.2007	2100–2300	47.020278, 85.960278
2	80	China, Xinjiang	Saur range, watershed, eastern part in 70–75 km SE of Zimunai, flat top, degraded alpine meadow, 12.7.2007	2440	47.026389, 86.042778
2	81	China, Xinjiang	Saur range, watershed, eastern part in 70–75 km SE of Zimunai, Kobresia community in meso-depression, 12.7.2007	2180	47.048611, 86.161667
2	82	China, Xinjiang	Zimunai county, Saur range, Mustau, N slope, valley of right tributary of Ul'un-Ulyasty near the border with Kazakhstan, alpine meadow, tundra, stonefielads, rocks, 10.7.2007	2900–3000	47.111250, 85.577778
2	83	Russia, Altai Territory	Charyshsky district, Korgonsky range, near the headwaters of Sentelek River, in mountain tundra, 19.8.1996	1900–2200	51.050000, 83.716667
2	84	Russia, Altai Territory	Charyshsky district, Korgonsky range, right bank of Gorelyi Korgon River near Korolyovskyi Belok Mt, 28.6.1998	1600–2000	50.983333, 83.733333
2	85	Russia, Altai Territory	Charyshsky district, Tigireksky range, left bank of Pervaya Shumishka River, 2.8.1997	1800	51.000000, 83.466667
2	86	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, headwaters of Bolshoy Tigirek River at 11.5 km S of Tigirek settlement and 3 km NW of Razrabotnaya Mt, rocks and stonefields, 21.7.2012	1540–1600	51.048056, 83.007500

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
2	87	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, Tigirek strict reserve, local summit at 1.4 km S from the Razrabotnaya Mt, mountain tundra with rocks, 23.6.2014	1700	51.015278, 83.028889
2	88	Russia, Altai Territory	Zmeinogorsky district, Tigireksky range, western part of the range at 5 km S of the community of Andreevsky, subalpine meadow, stones, 26.6.2003	1258	51.051667, 82.858500
2	89	Russia, Krasnoyarsk Territory	West Sayan Mts, Minusinsk, at road Minusinsk - Kizil, 2 km S of Buybinsky Pass, subalpine zone with Abies sibirica and Pinus sibirica on granite and other silicious bedrock, 21.6.2013	1500–1550	52.837513, 93.265000
2	90	Russia, Krasnoyarsk Territory	West Sayan Mts, Minusinsk, close to road Minusinsk - Kizil, 2 km E of Buybinsky Pass, E-exposed glacier cirque with mica-schist bedrock in subalpine zone, 21.6.2013	1550–1600	52.849154, 93.280855
2	91	Russia, Krasnoyarsk Territory	West Sayan Mts, Minusinsk, close to road Minusinsk - Kizil, 4 km E of Buybinsky Pass, flat mountain range with siliceous bedrock in alpine zone, 21.6.2013	1700	52.853889, 93.313611
2	92	Russia, Republic of Altai	Onguday district, Mt Sarlyk, c. 13 km E of pass Seminsky Pass, alpine zone, 8.7.2012	2000–2500	51.078087, 85.734416
2	93	Russia, Republic of Altai	Choya district, Karakoksha, settlement Uymen, Mt Sagani (2036 m), c. 40 km S of Karakoksha, 15.7.2012	1700–2030	51.529159, 86.746152
2	94	Russia, Republic of Altai	Kosh-Agach district, at gravel road between the lake Zerlyukal-Nur and Tepliy Kluch Pass, 31.7.2012	2400–2700	49.502373, 88.118887
2	95	Russia, Republic of Altai	Kosh-Agach district, camp “Dzhamalinski Kluchi”, c. 8 km N of pass Tepliy Kluch Pass, in valley of brook with granite boulders, 1.8.2012	2400	49.458179, 88.053923
2	96	Russia, Republic of Altai	Kosh-Agach district, hills W of Tepliy Kluch Pass, granite rocks / stones, 31.7.2012	3000	49.401268, 88.024687
2	97	Russia, Republic of Altai	Kosh-Agachsky district, Chuya Steppe, right bank of the Chuya River at 7 km upstream of Chagan-Uzin River junction, Populus laurifolia river-side forest, 4.7.2016	1730	50.071944, 88.410000
2	98	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, headwaters of the Ulandryk River, W slope of unnamed Mt (3061 m), mountain steppe and tundra, 6.7.2016	2800–2900	49.475000, 88.995833
2	99	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, left bank of the Bayan-Chagan River at 3.5 km upstream of the junction of the Karasu River, 13.6.2014	2500	49.527778, 88.777500
2	100	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, left bank of the Bayan-Chagan River at 5.5 km upstream of the junction of the Karasu River, 13.6.2014	2600–2800	49.511667, 88.780000
2	101	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, left bank of the Bayan-Chagan River at 6.5 km upstream of the junction of the Karasu River, 13.6.2014	2800–3000	49.505278, 88.777222

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
2	102	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, left bank of Yustyd River at 2 km downstream of Boguty and Naryngol Rivers junction, riparian Salix forest, 7.7.2013	2200	49.796944, 89.361944
2	103	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, right bank of the Bayan-Chagan River at 2.5 km upstream of the junction of the Karasu River, 14.6.2014	2460	49.534722, 88.765278
2	104	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, Sailyugem National Park, headwaters of the Ulandryk River, W slope of unnamed Mt (3061 m), mountain steppe and tundra, 7.7.2016	2250	49.651667, 89.077500
2	105	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, watershed of Bayan-Chagan and Sarzhemoty Rivers at 4 km to S from its junction, 14.6.2014	2550	49.535000, 88.758611
2	106	Russia, Republic of Altai	Kosh-Agachsky district, Ukok tableland, left bank of Ak-Alakha River at 1 km down stream from it's junction with Kalguty River, N and E slopes, rocks not far from river bank, 23.7.1998	2200	49.383333, 87.633333
2	107	Russia, Republic of Altai	Kosh-Agachsky district, Ukok tableland, left bank of the Ak-Akakha River 3 km down stream from the junction of Kara-Bulak River, 01.7.2012	2200	49.304167, 87.556667
2	108	Russia, Republic of Altai	Onguday district, c. 2 km E of Seminsky Pass, quartzite solitary rocks in forest-tundra zone, 8.7.2012	1800	51.042626, 85.635816
2	109	Russia, Republic of Altai	right bank of Chuya River upstream of the junction with Sukhodol Creek, telegraph-pole near the road, 1.7.2009	1600	50.251598, 87.885320
2	110	Russia, Republic of Altai	Ulagan district, NW part of Kuray Ridge, Aktash, surroundings of peak "2994" c. 10–15 km S of Ulagan Pass, 24 & 25.7.2012	2200–2950	50.394077, 87.676779
2	111	Russia, Republic of Altai	Ulagansky district, Kuraisky range, left bank of the Tchibitka River at the N coast of Tcheibekkel' Lake. Mountain tundra with Betula humilis, rock outcrops consisting small amounds of carbonates, 31.5.2005	1830	50.403333, 87.605000
2	112	Russia, Republic of Altai	Ust'-Koksinsky district, Katunsky range, the headwaters of Khazinikha River, N bank of the unnamed lake (elev. 2070 m). Stones fields and rocks, 19.7.2000	2100–2500	49.800000, 86.016667
2	113	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, headwaters of the Mugur River at 25 km W from Mugur-Aksy, alpine meadows and mountain tundras with stones, 12.7.2014	2600	50.348611, 90.086944
2	114	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, headwaters of the Mugur River at 27 km W from Mugur-Aksy, alpine meadows and mountain tundras with stones, 13.7.2014	2720	50.319722, 90.075278

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
2	115	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, headwaters of the Mugur River at 27.5 km W from Mugur-Aksy, alpine meadows and mountain tundras with stones, 13.7.2014	2800	50.309722, 90.068333
2	116	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, headwaters of the Mugur River at 28 km SW from Mugur-Aksy, mountain tundras, rocks, 14.7.2014	2900–3000	50.297500, 90.062222
2	117	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, left side of the Toolaity River's valley at 2.7 km upstream from the Eski-Toolaity lake, mountain tundras, stonefield, 5.7.2014	2700–2800	50.171944, 90.155833
2	118	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, left side of the Toolaity River's valley at 3.5 km upstream from the Eski-Toolaity lake, mountain tundras, stonefield, 4.7.2014	2450–2600	50.183333, 90.150000
2	119	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, left side of the Toolaity River's valley at 5 km upstream from the Eski-Toolaity lake, mountain tundras, stonefield, 7.7.2014	2550	50.193333, 90.146111
2	120	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, right side of the Khairykan River's valley at 3 km upstream from its mouth (Mugur River), alpine meadows and mountain tundras with stones, 11.7.2014	2400–2500	50.310556, 90.206389
2	121	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, right side of the Khairykan River's valley at 4 km upstream from its mouth (Mugur River), stonefields within alpine meadows and mountain tundras, 11.7.2014	2540	50.303056, 90.198611
2	122	Russia, Republic of Tyva	Mongun-Taiginsky district, Mongun-taiga massif, right side of the Khairykan River's valley at 4.5 km upstream from its mouth (Mugur River), stonefields within alpine meadows and mountain tundras, 11.7.2014	2550	50.300278, 90.195000
2	123	Russia, Republic of Tyva	West Sayan Mts, Ak-Dovurak, Ak-Sug, Enge-Beldir, 5 km SE of Sayansky Pass, at road A161, 9.7.2013	2050	51.691111, 89.945844
2	124	Russia, Republic of Tyva	West Sayan Mts, Ak-Dovurak, Ak-Sug, Enge-Beldir, glacier cirque in S-slope from Sayansky Pass, at road A161, close to border with Khakasia, 9.7.2013	2150–2200	51.699987, 89.887233
3	125	China, Xinjiang	Chinese Dzungaria, 40 km S from Kektogai, low branchgrass-wormwood-pigweed semidesert, 7.7.2007	940	46.604100, 89.586633
3	126	China, Xinjiang	Kabinsky range, at 10 km SW sattlement Purbe (Bai-Kaba), left bank of the Ak-Kaba River, steppe slopes with bushes, 31.7.2005	1375	48.637222, 86.698889
3	127	China, Xinjiang	Kabinsky range, at 22 km NNE settlement Keldynen-Bulak, the velley of Terekty River, Populus laurifolia forest, 31.7.2005	1050	48.473611, 86.691389

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
3	128	China, Xinjiang	Mongol'sky Altai range, valley of Irtysh River at 10 km E settlement Kektogoy, rocks, steppe slope, 7.8.2005	1300–1600	47.227778, 89.921667
3	129	China, Xinjiang	Mongol'sky Altai range, foothills of range at 40th km of the road Qinghe–ltai (30 km SW of Qinghe), desert steppe slopes, rocks, Achnatherum splendens community in meso-depressions, 1.8.2007	1280	46.512939, 90.058745
3	130	China, Xinjiang	Zimunai county, Saur range, Saur, N slope in 30 km south of Zimunai, after-forest meadow steppe with bushes, roadside, 10.7.2007	1760	47.244722, 85.723611
3	131	Russia, Altai Territory	Altayskoe district, Nizhnekayancha, SE-exposed limestone / granite cliffs above left bank of river Katun, in steppe zone, 19.5.2012	300–500	51.886200, 85.789320
3	132	Russia, Altai Territory	Charyshsky district, Korgonsky range, at 3 km SE of the community of Tulata, limestones on a SE slope of Mt, 23.5.1996	480–500	51.283333, 83.466667
3	133	Russia, Altai Territory	Charyshsky district, Korgonsky range, right bank of Sentelek River at 2 km upstream of the community of Sentelek, SE slope, stone fields covered by shrubs, 21.5.1996	600–900	51.266667, 83.700000
3	134	Russia, Altai Territory	Charyshsky district, Tigireksky range, at 1,5 km E of the community of Andreyevskoye, limestone rocks, 10.7.1996	700	51.116667, 82.850000
3	135	Russia, Altai Territory	Gorno-Altaysk, Sarasa, Rudnik, large limestone / schist cliff in SW-slope above river Sarasa at village, 4.7.2012	500–600	51.828464, 85.348389
3	136	Russia, Altai Territory	Krasnoshchokovsky district, Korgonsky range, right bank of Inya River at 4 km upstream from it's mouth, SW, S slopes, 12.6.1994	500–600	51.433333, 83.033333
3	137	Russia, Altai Territory	Uglovsky district, at 12 km E from the Borisovka settlement, 1 km SE from Bol'shoi Tassor Lake, desert communities on colored cleys, 8.7.2017	227	51.143208, 80.407771
3	138	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, in the visinity of the community of Tigirek, SE slope of Chainaya Mt, 1.5.2003	500–600	51.133333, 83.016667
3	139	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, left bank of Inya River at 4 km upstream from it's mouth, SW, S slopes near Plakun Mt, 13.6.1994	500–600	51.433333, 83.033333
3	140	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, right bank of Inya River at 2 km upstream of the community of Tigirek, Inskaya Mt,limestone rocks, 11.7.1996	600–800	51.150000, 83.066667
3	141	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, right bank of the Inya River, near the Yashchur Cave, steep SE slope, calcareous rocks (Silur) and Juniperus, 21.6.2017	590	51.168333, 83.035000

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
3	142	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, Tigirek strict reserve, at ca. 5 km NNW from the community of Tigirek, calcareous boulders outcrops at the S slop of the Mt (967.8 m), 6.5.2007	850	51.190667, 83.010167
3	143	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, Tigirek strict reserve, at ca. 5 km NNW from the community of Tigirk, calcareous rock outcrops at the S slop of the Mt (967.8 m), 6.5.2007	906	51.191500, 83.006083
3	144	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, Tigirek strict reserve, Khankharinsky cluster at 6.5 km NW from the community of Tigirek, forest-steppe, limestone rock outcrop at the local summit, 30.6.2015	920	51.195556, 82.978889
3	145	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, Tigirek strict reserve, Khankharinsky cluster left bank of the Dragunsky kluch crack, at 6.2 km NW from the community of Tigirek, W exposed limestone rock, 29.6.2015	870	51.186944, 82.969167
3	146	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, Tigirek strict reserve, Khankharinsky cluster left bank of the Dragunsky kluch crack, at 6.3 km NW from the community of Tigirek, forest-steppe, limestone rock outcrop, 30.6.2015	920	51.193056, 82.978333
3	147	Russia, Altai Territory	Krasnoshchokovsky district, Tigireksky range, Tigirek strict reserve, right bank of Dragunsky klyuch crack, Salix - Betula forest, 6.5.2007	808	51.183667, 82.973972
3	148	Russia, Altai Territory	Kur'insky district, Kolyvansky range, left bank of Belaya River at 5 km SE of the community of Podpalattsi, rocks on a SE slope of Mt, 5.7.1996	300	51.200000, 82.750000
3	149	Russia, Altai Territory	Soloneshensky district, Bashchelaksky range, right bank of the Anuy River at 4 km SE of the Topolnoye community, Pinus sylvestris forest, limestones, 21.7.2015	550	51.487222, 84.536389
3	150	Russia, Altai Territory	Srostki, c. 5 km SE of village, SW-exposed loess slopes above Katun river, 3.7.2012	250	52.403871, 85.779339
3	151	Russia, Altai Territory	Uglovsky district, at 12 km E from the Borisovka settlement, 1 km SE from Bol'shoi Tassor Lake, desert communities on colored cleys, 6.7.2017	220	51.141444, 80.40025
3	152	Russia, Altai Territory	Uglovsky district, at 12 km E from the Borisovka settlement, 1 km SE from Bol'shoi Tassor Lake, desert communities on colored cleys, 7.7.2017	228	51.142028, 80.401167
3	153	Russia, Altai Territory	Uglovsky district, at 12 km E from the Borisovka settlement, 1 km SE from Bol'shoi Tassor Lake, desert-type communities, 7.7.2017	218	51.142028, 80.403528
3	154	Russia, Altai Territory	Ust'-Kalmansky district, at 3 km W from the Ogni settlement, foothills of the Altay Mts., right bank of the Zemlyanukha River, open siliciose outcrops of the top of the hill, SW slope, 9.4.2014	390	51.894444, 83.484722

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
3	155	Russia, Krasnoyarsk Territory	12 km S of town Sharipovo, sun-exposed limestone outcrops on S-slope in forest-steppe, 17.6.2013	400	55.415839, 89.160823
3	156	Russia, Krasnoyarsk Territory	18 km S of town Sharipovo, sun-exposed siliceous outcrops on W-slope in forest-steppe, 17.6.2013	430	55.375562, 89.237222
3	157	Russia, Republic of Altai	at road Biysk - Gorno-Altaysk, between Bistryanka and Mayma, W-exposed slope above Katun river, 3.7.2012	250	52.095243, 85.923706
3	158	Russia, Republic of Altai	Kosh-Agach district, Kuray Steppe, gneiss hills c. 4 km W of Kuray, 11 & 12.7.2012	1500–1550	50.230994, 87.882056
3	159	Russia, Republic of Altai	Onguday district, confluence of rivers Katun and Chuya, c. 7 km SE of Inya, limestone / schist / gneiss outcrops, 10&20.7.2012	800–900	50.399600, 86.67561
3	160	Russia, Republic of Altai	Ongudaysky district, Aigulaksky range, left bank of Chuya River at the vicinity of Akbom settlement, E exposed steep limestone rock, 8.7.2016	1050	51.360556, 87.038333
3	161	Russia, Republic of Altai	Ongudaysky district, Aigulaksky range, right bank of Chuya River near the its mouth. Around of the S slope of the Bom Bachiktu-Kaya, dry steppe, 29.5.2005	850	50.408333, 86.675000
3	162	Russia, Republic of Altai	Ongudaysky district, Seminsky range, Vicinity of the community of Khabarovka, at the right bank of Ursul River near it's flows into the Malyi Ilgumen' River, 29.5.2005	725	50.725000, 86.300000
3	163	Russia, Republic of Altai	Ulagan district, Aktash, SW-exposed steep slopes above right bank of brook Yarliamri, rockey steppe with limestone and siliceous outcrops, 26.7.2012	1600–1800	50.335726, 87.647602
3	164	Russia, Republic of Altai	Ulagan district, Balykcha, in village Koo, 21.7.2012	500	51.096864, 87.897492
3	165	Russia, Republic of Altai	Ulagan district, Balykcha, Kok-Pash, siliceous hill in valley of river Chulyshman, c. 2 km S of village, 22.7.2012	500	51.179892, 87.772869
3	166	Russia, Republic of Altai	Ulagan district, in valley of river Chulyshman below pass Katu-Yaryk, 23.12.2012	600	50.921904, 88.213935
3	167	Russia, Republic of Altai	Ulagan district, NE/E-exposed rocks / stones / steppe terrace above left bank of river Chulyshman between pass Katu-Yaryk and village Koo, 21&23.7.2012	600	50.999400, 88.058504
3	168	Russia, Republic of Altai	Ulagan district, pass Katu-Yaryk above river Chulyshman, NE of Ulagan, gneiss ridge, 21.7.2012	1100–1200	50.913350, 88.215153
3	169	Russia, Republic of Khakasia	20 km N of town Shira, quartzite, limestone and schist outcrops in short-grass steppe, 18.6.2013	410	54.663333, 89.843045
3	170	Russia, Republic of Khakasia	Tashtip, steppes (with Larix - Betula forests on N-slopes) on hills between villages Nizhnaya Teya and Poltakov, with sandstone and schist outcrops, 10.7.2013	480	52.937229, 90.091389

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
3	171	Russia, Republic of Khakasia	Znamenka, 1 km N of village Karasuk, W-exposed, sunny limestone outcrops in forest-steppe, 19.6.2013	470	54.318901, 90.610545
3	172	Russia, Republic of Tyva	Kizil, Sush, 10 km E of Begreda settlement, W-NW exposed siliceous outcrops in steppe above right bank of river Bolshoy Yenisey, 23.6.2013	660–800	52.023895, 94.405278
3	173	Russia, Republic of Tyva	10 km NE of village Shagonar, limestone and siliceous hills above left bank of river Yenisey, 7.7.2013	600–800	51.569438, 93.043611
3	174	Russia, Republic of Tyva	Kizil, 2.5 km W of village Ust'-Elegest, N-faced siliceous cliff in steppe, 6.7.2013	660	51.550007, 94.054156
3	175	Russia, Republic of Tyva	Russia, Republic of Tuva, Kizil, about 4 km NE of village Khaya-Bazhi, schist and limestone hills at southern margin of Akademika Obrucheva range, 25.6.2013	950–1500	51.730833, 94.750833
3	176	Russia, Republic of Tyva	Sarig-Sep, 2 km NE of village Derzig-Aksi, siliceous and limestone cliffs on W and S slopes with steppe (in forest-steppe territory), 5.7.2013	820	51.473618, 95.635278
3	177	Russia, Republic of Tyva	Sarig-Sep, Buren-Bay-Khaak, concrete gutter in steppe at village, 4.7.2013	840	51.199173, 95.525833
3	178	Russia, Republic of Tyva	Shagonar, 2 km S of village Bayan-Kol, on opposite side of river Yenisey, siliceous outcrops in steppe, 7.7.2013	610	51.556938, 93.538889
4	179	China, Xinjiang	Mongol'sky Altai range, Kungeytytau mts., upper reaches of Yelt-gol in 15 km upper the mouth of Duntsa-Khe, subalpine and alpine meadows, near the snow, rocks, steppe slopes, 23.7.2007	2800–3040	48.060278, 88.856944
4	180	China, Xinjiang	Zimunai county, Saur range, eastern part, northern slope, valley of Tastykarasu ca. 50 km SE of Zimunai, steppe slopes, rocks, 12.7.2007	1630	47.192222, 86.115000
4	181	Russia, Republic of Altai	Kosh-Agach district, Kosh-Agach, Telengit-Sortogoy, lime-rich schist outcrops in S-slopes of Kuray Ridge (easternmost part), c. 6 km N of village, 2.8.2012	2000–2100	50.081700, 88.718879
4	182	Russia, Republic of Altai	Kosh-Agach district, Kosh-Agach, valley of brook Tarchata, c. 10 km S of military post Tarkhata, schist rocks at brook, 1.8.2012	2200	49.683557, 88.451413
4	183	Russia, Republic of Altai	Kosh-Agach district, Kuray Steppe, limestone hills c. 4 km W of Kuray, 11-12.7.2012	1600–1680	50.237240, 87.872188
4	184	Russia, Republic of Altai	Kosh-Agach district, SE part of Kuray Ridge, NE of village Chagan-Uzun, 27-28.7.2012	2000–2700	50.107781, 88.457764
4	185	Russia, Republic of Altai	Kosh-Agach district, SE part of Kuray Ridge, NE of village Chagan-Uzun, 28-29.7.2013	2700–3100	50.138212, 88.493480
4	186	Russia, Republic of Altai	Kosh-Agachsky district, at 2 km E of Kurai, Kurai Steppe, on crushed stone (detritus), 31.5.2005	1562	50.244722, 87.897500
4	187	Russia, Republic of Altai	Kosh-Agachsky district, Chuya Steppe, headwaters of the Balakhan River at 9.5 km N of Kosh-Agach, dry steppe, rock outcrops, 5.7.2016	2150	50.079167, 88.701111

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APPENDIX 1. (Continued)

Environmental class (numbering follows the text)	Order of localities for Appendix 2	Country, region	Locality	Altitude, m a.s.l.	Coordinates
4	188	Russia, Republic of Altai	Kosh-Agachsky district, Chuya Steppe, right bank of the Tydtuyaryk River near its junction with Chuya River, rock outcrops, dry steppe, 4.7.2016	1760	50.071667, 88.413889
4	189	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, right bank of the Bayan-Chagan River at 2.5 S from its junction with the Karasu River, 15.6.2014	2680	49.533611, 88.776667
4	190	Russia, Republic of Altai	Kosh-Agachsky district, Sailjugem range, right bank of the Bayan-Chagan River at 2.5 S from its junction with the Karasu River, 15.6.2014	2630	49.531944, 88.779167
4	191	Russia, Republic of Altai	Kosh-Agachsky district, Ukok tableland, left bank of Bolshoi Shebety River at 8 km upstream of Malyi Shebety River mouth, high mountain steppe, 7.7.2012	2230	49.670000, 89.005000
4	192	Russia, Republic of Tyva	12 km NE of settlement Tsagan-Tologoy, 13 km N of border crossing to Mongolia, limestone hills with steppe or lit Larix forest, 29.6.2013	1400–1660	50.065549, 95.585556
4	193	Russia, Republic of Tyva	Erzin, 10 km E of settlement Tsagan-Tologoy, 4 km N of border crossing to Mongolia, siliceous outcrops in steppe, 27.6.2013	1400	49.993056, 95.627489
4	194	Russia, Republic of Tyva	Erzin, 9 km NE of village Moren, W-S-E slopes of limestone massif with steppe and lit Larix forest, 1.7.2013	1550–1950	50.358889, 95.461667

APPENDIX 2. List of recorded species with locality and voucher data. Numbers of localities are linked to the order in Appendix 1. See Methods for voucher depositions. Names in inverted commas are *Caloplaca* sensu lato; i.e. not belonging to *Caloplaca* sensu Arup *et al.* (2013).

Species	Localities and vouchers
Amundsenia approximata	93 (Vondrák 18142)
Athallia cerinelloides	16 (Davydov 2137), 30 (Davydov 10824), 34 (Davydov 10813), 61 (Vondrák 18034), 67 (Vondrák 18303), 147 (Davydov 10763), 176 (Vondrák 18390), 192 (Vondrák 18321)
Athallia holocarpa	2 (Davydov 14137), 15 (Davydov 1150), 16 (Davydov 1790, 1781), 60 (Vondrák 18072, 10332), 67 (Vondrák 18417), 69 (Vondrák 18295, 18286; Frolov 1944, 1867), 90 (Frolov 1994), 92 (Vondrák 18098), 93 (Vondrák 18109; Frolov 559), 124 (Vondrák 18301), 136 (Davydov 556, 537, 533, 526, 522), 155 (Vondrák 18362), 165 (Vondrák 18158)
Athallia pyracea	1 (Davydov 5927), 2 (Davydov 14139), 9 (Davydov 11346), 12 (Davydov 10873), 34 (Davydov 10879), 38 (Davydov 10266, 10261, 10259, 10815, 10214, 10176, 16529), 39 (Davydov 10135), 43 (Davydov 10552 & Konoreva), 44 (Vondrák 18697), 46 (Frolov 1900), 59 (Vondrák 10414), 62 (Vondrák 18070, 18039), 65 (Vondrák 18411, 18263), 155 (Vondrák 18248), 164 (Vondrák 18149)
Athallia saxifragarum	67 (Frolov 1311), 72 (Davydov 10883), 103 (Davydov n.s.), 124 (Vondrák 18313), 181 (Frolov 582), 185 (Vondrák 12714, 12712, 12561)
Athallia sp.	184 (Frolov 1599, Vondrák 18073)
Blastenia ammiospila	72 (Davydov 6897, 10882), 73 (Davydov 5835), 77 (Davydov 5904), 80 (Davydov 10864, 6449), 83 (Davydov 10848), 85 (Davydov 2234), 86 (Davydov 16695), 87 (Davydov 11213 & Yakovchenko), 91 (Vondrák 18290), 92 (Vondrák 18043, 10329), 93 (Vondrák 18129), 96 (Vondrák 18136), 105 (Davydov 11237 & Yakovchenko), 110 (Vondrák 18058, 10223), 114 (Davydov 11191 & Yakovchenko), 115 (Davydov 11227 & Yakovchenko), 116 (Davydov 11232 & Yakovchenko, 11228 & Yakovchenko), 118 (Davydov 11192 & Yakovchenko, 11242 & Yakovchenko), 119 (Davydov 14047 & Yakovchenko), 124 (Vondrák 18316), 130 (Davydov 6898, 6505), 179 (Davydov 6894, 10896)
Blastenia furfuracea	6 (Davydov 12284), 17 (Davydov 10871), 19 (Davydov 11241 & Yakovchenko), 20 (Davydov 5220), 27 (Davydov 10713), 29 (Davydov 14136), 32 (Davydov 10738), 75 (Davydov 14144, 14135), 67 (Vondrák 11096), 186 (Davydov 17290)
Blastenia sp.	19 (Davydov 11222 & Yakovchenko)
Bryoplaca jungermanniae	83 (Davydov 1047), 92 (Vondrák 18041), 94 (Vondrák 10364), 100 (Davydov 1204), 110 (Vondrák 18055, Frolov 1587), 113 (Davydov 11193 & Yakovchenko), 114 (Davydov 11194 & Yakovchenko), 115 (Davydov 12223), 116 (Davydov 11229 & Yakovchenko, 11230 & Yakovchenko)
Bryoplaca tetraspora	74 (Davydov 10899), 82 (Davydov 10846), 96 (Vondrák 18062), 110 (Frolov 1537, Vondrák 18057)
Calogaya arnoldii	41 (Davydov 6934), 54 (Vondrák 18093), 60 (Frolov 1591), 69 (Vondrák 18323), 93 (Frolov 1592), 135 (Frolov 1478)
Calogaya biatorina	21 (Davydov 17200), 108 (Frolov 472, Vondrá 18087), 118 (Davydov 11215 & Yakovchenko), 132 (Davydov 10859), 158 (Vondrá 18141), 183 (Vondrá 18101, 10380), 184 (Vondrá 18038), 185 (Vondrá 18154), 188 (Davydov 17251), 190 (Davydov 11200 & Yakovchenko), 192 (Vondrá 18436, 18400, 18384), 194 (Vondrá 18297, 18269, 18434)
Calogaya biatorina subsp. asiatica	158 (Vondrák 18024), 175 (Frolov 1822, 819), 183 (Frolov 180, Vondrák 18094), 185 (Vondrák 12707, 12665), 192 (Frolov 1969, 1959), 194 (Frolov 1364)
Calogaya bryochrysion	53 (Davydov 11499), 61 (Frolov 1493), 102 (Davydov 11498), 124 (Vondrák 11086, 18314), 184 (Frolov 1586, Vondrák 10372, 10371)
Calogaya decipiens	69 (Vondrák 18288), 174 (Vondrák 12553, Frolov 1773) 185 (Vondrák 18153), 187 (Davydov 17248), 190 (Davydov 11201 & Yakovchenko)
Calogaya ferrugineoides	125 (Davydov 11221), 151 (Davydov 17046 & Yakovchenko), 152 (Davydov 17049 & Yakovchenko), 181 (Vondrák 18061), 183 (Vondrák 12708), 184 (Vondrák 10354, 18060)
Calogaya pusilla	157 (Vondrák 18147), 171 (Frolov 1923, Vondrák 18221)
Calogaya saxicola s.lat.	47 (Vondrák 18111), 51 (Vondrák 18080), 124 (Vondrák 12558, 12559, 18398, 18380), 137 (Davydov 17045 & Yakovchenko)

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APPENDIX 2. (Continued)

Species	Localities and vouchers
Calogaya schistidii	185 (Frolov 1586), 192 (Vondrák 18419), 194 (Frolov 1980)
Calogaya xanthoriella	129 (Davydov 10857), 184 (Frolov 1598)
Calogaya zoroasteriorum	184 (Frolov 1597, Vondrák 18084, 10308)
'Caloplaca' ahtii	7 (Davydov 16793), 12 (Davydov 10874), 28 (Davydov 10855), 34 (Davydov 10885,10877), 44 (Vondrák 18245), 55 (Davydov 14149), 59 (Vondrák 10404), 63 (Vondrák 18267), 64 (Vondrák 18424), 66 (Vondrák18338, 18244), 67 (Vondrák 18227, Frolov 1312), 68 (Vondrák 18406), 176 (Vondrák 18387, 18369)
'Caloplaca' anularis	175 (Frolov 1823), 183 (Frolov 182), 184 (Vondrák 10313), 185 (Vondrák 10304, 9927, Frolov 160, 86, 85), 192 (Vondrák 18201, Frolov 2080, 1956), 194 (Vondrák 12696, 12694,и Frolov 1985, 1350)
'Caloplaca' atroflava	60 (Frolov 1519)
'Caloplaca' bicolor	181 (Vondrák 10373), 185 (Vondrák 10399, Frolov 91), 190 (Davydov 11203 & Yakovchenko)
'Caloplaca' cf. bohlinii	173 (Vondrák 18215), 192 (Vondrák 18352, 18216), 194 (Vondrák 12693)
'Caloplaca' borealis	45 (Frolov 1797), 68 (Vondrák 18425), 89 (Vondrák 11126, 11073, Frolov 1893)
Caloplaca cerina	3 (Davydov 14148, 5956), 4 (Davydov 11224), 10 (Davydov 10772 & Zhikhareva), 12 (Davydov 10875), 16 (Davydov 16719, 1872), 19 (Davydov 11217 & Yakovchenko), 30 (Davydov 10826), 32 (Davydov 14143), 33 (Davydov 1935), 34 (Davydov 10878, 10767), 35 (Davydov 10893), 38 (Davydov 10265, 10258, 10230, 10175, Davydov 10515 & Konoreva,), 39 (Davydov 10134), 42 (Davydov 10095), 43 (Davydov 10551 & Konoreva), 44 (Vondrák 18698), 46 (Frolov 1901), 59 (Vondrák 10413, 10405), 65 (Vondrák 18410, 18262, Frolov 1993, 1805), 66 (Vondrák 18339, 18311), 67 (Vondrák 11104, 18302), 87 (Davydov 11216 & Yakovchenko), 127 (Davydov 11284), 136 (Davydov 557, 538, 534, 525, 521), 155 (Vondrák 18247), 166 (Vondrák 18107), 176 (Vondrák 18389, 18388, 18368), 177 (Vondrák 18414, Frolov 1762)
Caloplaca chlorina	2 (Davydov 14140), 18 (Davydov 2268), 157 (Vondrák 10334), 174 (Vondrák 18682)
'Caloplaca' conversa	47 (Vondrák 10289), 48 (Vondrák 10302), 69 (Frolov 1909), 131 (Vondrák 10335, 10273, Frolov 158), 172 (Vondrák 18232), 173 (Vondrák 18344), 175 (Vondrák 18240)
'Caloplaca' epithallina	57 (Vondrák 18049, Frolov 487), 63 (Frolov 1846), 69 (Frolov 1949, 1795, Vondrák 18287), 75 (Davydov 6678), 92(Vondrák 10301), 93 (Vondrák 18079), 95 (Vondrák 18047), 101 (Davydov 11198 & Yakovchenko), 102 (Davydov 11199 & Yakovchenko), 106 (Davydov 2243), 108 (Vondrák 10269), 122 (Davydov 14058 & Yakovchenko), 148 (Davydov 1927), 158 (Vondrák 10312, 18048, 18138, Frolov 146). 163 (Vondrák 10338), 167 (Vondrák18122), 168 (Vondrák 18125, 10285, Frolov 1573), 172 (Frolov 1839), 184 (Vondrák 10339), 189(Davydov 11214 & Yakovchenko)
'Caloplaca' exsecuta	88 (Davydov 5510), 124 (Vondrák 11110)
Caloplaca fluviatilis	67 (Frolov 1313, Vondrák 18213), 68 (Frolov 630, 631, 634, Vondrák 18229)
'Caloplaca' grimmiae	124 (Vondrák 18299), 138 (Davydov 5511), 158 (Vondrák 18134), 172 (Frolov 1840), 174 (Frolov 1771), 191 (Vondrák 19064)
'Caloplaca' helygeoides	5 (Davydov 16892), 31 (Davydov 12297 & Zamora, 12296 & Zamora), 60 (Vondrák 10454, Frolov 1518), 68 (Vondrák 18370, Frolov 643, 632, 2067), 76 (Davydov 14459), 89 (Vondrák 12655), 110 (Vondrák 10421), 112 (Davydov 12294), 124 (Vondrák 11102, Frolov 1438, 1437, 1237)
Caloplaca isidiigera	90 (Vondrák 12697, 12654, 12653, Frolov 1877) 93 (Vondrák 10315), 124 (Vondrák 110990,
'Caloplaca' molariformis	181 (Vondrák 10224)
Caloplaca monacensis	61 (Vondrá 18032)
'Caloplaca' percrocata	112 (Davydov 11295)
'Caloplaca' pratensis	155 (Vondrák 11092, 2060, 2059, Frolov 1275), 169 (Vondrák 2094, 2093, Frolov 1271), 170 (Vondrák 11972), 172 (Frolov633, 622, 621, 619), 181 (Vondrák 10419), 194 (Vondrák 18363, Frolov 1361, 1348)
'Caloplaca' raesaenenii	65 (Frolov 1804), 107 (Davydov 10897), 130 (Davydov 10852), 141 (Davydov 172240, 150 (Vondrák 18076, 103140, Frolov 1588), 154 (Davydov 11205 & Yakovchenko), 155 (Vondrák 18246, Frolov 1897, 1727, 1896), 158 (Vondrák 10282), 172 (Frolov 1837, Vondrák 19044), 175 (Frolov 1916), 178 (Vondrák 18318, Frolov 1723), 191 (Davydov 10888)

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APPENDIX 2. (Continued)

Species	Localities and vouchers
'Caloplaca' scrobiculata	185 (Vondrák 9933)
'Caloplaca' soralifera	59 (Vondrák 10286), 60 (Vondrák10320), 169 (Vondrák 2095), 170 (Vondrák 18397)
'Caloplaca' sorocarpa	90 (Vondrák 12695)
'Caloplaca' sp., unknown species	68 (Vondrák 18687)
Caloplaca stillicidiorum	2 (Davydov 14138), 63 (Frolov 1989), 67 (Frolov 1310, Vondrák 18228), 68 (Vondrák 18407), 72 (Davydov 10881), 75 (Davydov 6878), 78 (Davydov 10854), 79 (Davydov 11225), 80 (Davydov 10863, 6890), 81 (Davydov 10903, 10894, 6881, 6444), 98 (Davydov 16645), 99 (Davydov 11209 & Yakovchenko), 100 (Davydov 11207 & Yakovchenko), 105 (Davydov 11234 & Yakovchenko), 107 (Davydov 10898), 110 (Frolov 1536), 116 (Davydov 11233 & Yakovchenko), 123 (Vondrák 18694), 124 (Vondrák 18315), 126 (Davydov 14142), 130 (Davydov 10851, 10850, 6899), 135 (Vondrák 18054, 10318), 154 (Davydov 11206 & Yakovchenko) 155 (Frolov 1898, 1726), 172 (Frolov 1838), 175 (Frolov 1914), 178 (Vondrák 18319), 184 (Vondrák 18085), 185 (Vondrák 10352)
Caloplaca subalpina	90 (Frolov 1880, Vondrák 12652, 12658, 12667, 12673)
'Caloplaca' teicholyta	155 (Frolov 2044, Vondrák 18355), 169 (Frolov 1908), 194 (Vondrák 12688)
'Caloplaca' aff. tianshanensis	163 (Vondrák 10457)
'Caloplaca' transcaspica	158 (Frolov 208), 167 (Frolov 228), 183 (Frolov 156), 185 (Vondrák 10435)
Caloplaca turkuensis	68 (Vondrák 18405)
'Caloplaca' xerica	52 (Frolov 175, Vondrák 10292)
'Caloplaca' zeorina	185 (Vondrák 9928)
Flavoplaca flavocitrina	26 (Davydov 17240), 47 (Vondrák 18112), 48 (Vondrák 18099), 59 (Vondrák 12679), 69 (Frolov 1945, Vondrák 18324), 135 (Vondrák 18152), 157 (Vondrák 18157), 174 (Vondrák 18348)
Flavoplaca oasis	37 (Frolov 539, Vondrák 18162), 48 (Vondrák 18083), 49 (Vondrák 18066), 131 (Vondrák 10349), 142 (Davydov 10868), 157 (Vondrák 18156), 163 (Vondrák 18160), 169 (Frolov 2026, 2027, 2029, Vondrák 18222), 171 (Vondrák 18255, 18403, 18415), 172 (Frolov 1997), 173 (Frolov 2017, Vondrák 18347), 175 (Frolov 2002, Vondrák 18256), 176 (Frolov 1890), 178 (Frolov 1807), 183 (Vondrák 18040), 192 (Frolov 1952, 1967, 1968, Vondrák 18382, 18432), 194 (Vondrák 18217, 18220, 18251, 18335)
Gyalolechia bracteata	143 (Davydov 10349), 159 (Vondrák 10278), 194 (Frolov 1979, Vondrák 18293)
Gyalolechia epiphyta	3 (Davydov 14843), 163 (Vondrák 18139), 183 (Vondrák 10319, 12710), 185 (Vondrák 10353), 194 (Frolov 1325, 1327)
Gyalolechia flavorubescens	36 (Davydov 10590), 61 (Vondrák 18031, 18063), 161 (Davydov 10502), 166 (Vondrák 18135)
Gyalolechia flavovirescens	48 (Vondrák 18082), 49 (Frolov 439, Vondrák 18096), 55 (Davydov 11238), 59 (Vondrák 10275), 60 (Frolov 1520), 69 (Vondrák 18333), 131 (Vondrák 18077), 138 (Davydov 5517), 155 (Frolov 1853, Vondrák 18354), 157 (Vondrák 10434, 18117), 159 (Vondrák 18035), 162 (Davydov 10856), 166 (Vondrák 18126), 167 (Vondrák 10344), 168 (Frolov 1575, Vondrák 10247), 169 (Frolov 1861, 1906, Vondrák 18300), 171 (Vondrák 18416), 172 (Vondrák 18292, 18322), 174 (Frolov 1752, Vondrák 18359), 194 (Vondrák 18372)
Gyalolechia fulgens	155 (Vondrák 18219)
Gyalolechia lenae	61 (Frolov 1495), 79 (Davydov 10886), 121 (Davydov 11212 & Yakovchenko), 133 (Davydov 10872), 135 (Frolov 66, Vondrák 18119), 144 (Davydov 14887), 145 (Davydov 14886), 149 (Davydov 12281), 155 (Frolov 1895, Vondrák 18448), 159 (Frolov 421), 160 (Davydov 17218), 168 (Frolov 1566, Vondrák 10266), 171 (Vondrák 18421), 172 (Vondrák 18276), 173 (Frolov 2014), 175 (Frolov 2001), 185 (Vondrák 10362), 192 (Frolov 1965, Vondrák 18689), 194 (Frolov 1356, 1987, Vondrák 18272)

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Species	Localities and vouchers
Gyalolechia ussuriensis	42 (Davydov 11220), 46 (Frolov 1899, 1902, Vondrák 13417), 50 (Vondrák 18045), 61 (Vondrák 18033, 18064), 135 (Vondrák 10317), 164 (Vondrák 18146), 166 (Vondrák 18106), 173 (Frolov 2018, Vondrák 18446), 176 (Vondrák 18367, 18431)
Leproplaca cirrochroa	135 (Frolov 75, Vondrák 18120), 157 (Vondrák 18118, 18121), 162 (Davydov 5779)
Leproplaca obliterans	91 (Frolov 1791, Vondrák 12662)
Leproplaca xantholyta	185 (Vondrák 18065)
Pachypeltis insularis	184 (Vondrák 10340), 185 (Frolov 87, Vondrák 12709), 194 (Frolov 1351)
Pachypeltis intrudens	114 (Davydov 11246 & Yakovchenko), 182 (Vondrák 18059), 185 (Frolov 56)
Pachypeltis aff. pachythallina	185 (Vondrák 12649, 12706), 192 (Vondrák 18688)
Pachypeltis phoenicopta	158 (Vondrák 18027), 184 (Vondrák 18026), 193 (Vondrák 18695)
Parvoplaca tiroliensis	74 (Davydov 10901), 75 (Davydov 6876, 6877), 79 (Davydov 11226, 14844), 80 (Davydov 10865), 81 (Davydov 10904, 10895), 92 (Vondrák 18042), 94 (Vondrák 10357, 10365), 96 (Vondrák 18137), 100 (Davydov 11208 & Yakovchenko), 103 (Davydov 11236 & Yakovchenko), 110 (Frolov 1535, Vondrák 18056, 18144), 114 (Davydov 11195 & Yakovchenko), 116 (Davydov 11231 & Yakovchenko), 124 (Vondrák 18317), 130 (Davydov 10849, 10853), 185 (Frolov 1501, Vondrák 10350, 10351, 12713)
Polycauliona candelaria	8 (Davydov 11358 & Zhikhareva, 11365 & Zhikhareva), 11 (Davydov 11339 & Zhikhareva), 14 (Davydov 117), 24 (Davydov 10354), 40 (Davydov 385), 58 (Davydov 17249), 139 (Davydov 377)
Pyrenodesmia chalybaea	135 (Frolov 114, 940), 140 (Davydov 2284), 142 (Davydov 10867), 146 (Davydov 16890, 16897)
Pyrenodesmia concreticola	150 (Frolov 1561)
Pyrenodesmia erodens	135 (Frolov 113, 133, Vondrák 10439), 171 (Frolov 2058, Vondrák 18307), 173 (Frolov 1269, Vondrák 18361, 18413), 175 (Frolov 1268, 1270, Vondrák 12755), 185 (Frolov 211, 233, Vondrák 10420, 10422), 192 (Frolov 2072, Vondrák 18386, 18422), 194 (Frolov 1346, 2069)
Pyrenodesmia micromontana	124 (Vondrák 11083), 185 (Frolov 164)
Pyrenodesmia microstepposa	158 (Frolov 81), 169 (Frolov 1272, 2096, Vondrák 11107), 170 (Vondrák 11111), 177 (Frolov 2062, Vondrák 11071, 18375), 184 (Vondrák 10436)
Pyrenodesmia variabilis	15 (Davydov 1140), 25 (Davydov 11218 & Yakovchenko), 135 (Vondrák 10440), 155 (Vondrák 18341), 171 (Frolov 2057, Vondrák 18254, 18402), 175 (Frolov 1265, 1266, Vondrák 12757), 192 (Frolov 2076, Vondrák 12683, 18283), 194 (Frolov 1345, Vondrák 12680, 18253)
Rufoplaca arenaria sensu lato	68 (Vondrák 18371, 18693)
Rufoplaca sp. 1	49 (Frolov 560, 562, 1550, Vondrák 18052), 54 (Frolov 459), 57 (Frolov 497), 61 (Frolov 1492, 1578), 67 (Frolov 1314, Vondrák 18294, 18700), 69 (Frolov 1866, 1943, 1948, Vondrák 18296), 93 (Vondrák 10347), 124 (Vondrák 11098, 11103), 156 (Frolov 1883), 165 (Vondrák 10346, 18091), 168 (Frolov 1526, 1565, 1594), 176 (Frolov 1730, Vondrák 18198), 182 (Frolov 101, 162, Vondrák 10427), 193 (Vondrák 18277, 18330)
Rufoplaca sp. 2	96 (Vondrák 9924), 123 (Vondrák 18681)
Rufoplaca sp. 3	22 (Davydov 17245 & Yakovchenko)
Rufoplaca subpallida sensu lato	47 (Vondrá 18131), 49 (Vondrá 18067), 59 (Vondrá 9929), 60 (Vondrá 9922, 10345, 10348), 68 (19241), 91 (Vondrá 18691)
Rusavskia dasanensis	37 (Frolov 543, Vondrák 18114), 63 (Vondrák 18210), 69 (Vondrák 18204), 135 (Frolov 67, 89, Vondrák 18102), 155 (Vondrák 18420), 156 (Frolov 2035, Vondrák 18328), 157 (Vondrák 18124), 159 (Vondrák 18036), 169 (Frolov 1856, Vondrák 18430), 171 (Frolov 2039), 172 (Vondrák 18242, 18258, 18275), 174 (Frolov 1703, 1751, Vondrák 18358), 175 (Vondrák 18260, 18279), 176 (Frolov 1732, Vondrák 11115), 177 (Frolov 1925, Vondrák 18376), 178 (Frolov 1719, 1722, Vondrák 18409), 183 (Vondrák 9945), 192 (Vondrák 18284, 18383, 18392, 18418), 194 (Vondrák 18259, 18270)

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Species	Localities and vouchers
Rusavskia elegans senasu lato (with large thalli)	63 (Vondrák 18209), 91 (Vondrák 18332), 108 (Vondrák 18104), 192 (Vondrák 18447)
Rusavskia elegans senasu lato (with small thalli)	51 (Vondrák 18081), 63 (Vondrák 18208, 18441), 67 (Vondrák 18212), 68 (Vondrák 18423), 69 (Vondrák 18308, 18326), 91 (Frolov 1871), 93 (Vondrák 18143), 108 (Vondrák 18105), 124 (Vondrák 18381), 158 (Vondrák 18030), 163 (Vondrák 10293, 18133), 169 (Frolov 1857, Vondrák 118401), 172 (Vondrák 18237, 18257, 18264, 18273), 174 (Vondrák 18336), 175 (Frolov 1817, 1821, 1824), 177 (Frolov 1763, 1924, Vondrák 18377), 178 (Vondrák 18437), 185 (Vondrák 10417), 192 (Vondrák 18340, 18364), 194 (Vondrák 18252)
Rusavskia sorediata	69 (Vondrák 18205), 90 (Frolov 1910), 108 (Vondrák 18086), 156 (Vondrák 18329)
Rusavskia sp. 1 (Xanthoria-like)	63 (Vondrák 18408), 135 (Frolov 1479, Vondrák 18103), 156 (Vondrák 18327), 157 (Vondrák 18123), 171 (Frolov 2038), 172 (Vondrák 18274, 18320), 174 (Frolov 1701, Vondrák 18404), 192 (Vondrák 18207)
Rusavskia sp. 2 (with appressed lobes)	158 (Vondrák 18161), 175 (Vondrák 18211)
Seirophora contortuplicata	119 (Davydov 16846 & Yakovchenko), 120 (Davydov 16838 & Yakovchenko), 140 (Davydov 5975), 144 (Davydov 16837), 181 (Frolov 1049), 183 (Vondrák 9949, 10270), 185 (Frolov 586), 187 (Davydov 16839), 188 (Davydov 16840, 16841), 192 (Frolov 1964, Vondrák 18360), 194 (Frolov 1385)
Seirophora lacunosa	153 (Davydov 5888 & Yakovchenko)
Squamulea sp.	174 (Vondrák 18682)
Variospora dolomiticola	48 (Vondrák 18047), 107 (Davydov 10884), 159 (Vondrák 18037), 169 (Vondrák18304), 170 (Vondrák 18433), 175 (Frolov 2003, Vondrák 18223), 176 (Vondrák 18685), 178 (Frolov 1718, 1721), 181 (Vondrák 10370, 10384), 183 (Frolov 201, Vondrák 10310), 184 (Vondrák 10363), 185 (Vondrák 10398), 192 (Frolov 1973, 1960, Vondrák 18218, 18282, 18427), 194 (Frolov 1341, 1981, 1982, 1988, Vondrák 18202, 18268)
Variospora sororicida	155 (Vondrák 18350), 158 (Frolov 90, Vondrák 18046, 18069, 18071), 159 (Vondrák 10450), 163 (Vondrák 18140), 169 (Frolov 1860, 2024, Vondrák 18285), 170 (Vondrák 18399), 172 (Frolov 1835, Vondrák 18291), 173 (Frolov 2084), 175 (Vondrák 18280, 18692), 181 (Vondrák 10396), 184 (Vondrák 10455), 194 (Frolov 1357, 1986, 1990, Vondrák 12682, 12686, 18357, 18438)
Xanthocarpia crenulatella	37 (Frolov 540), 49 (Vondrák 18068), 55 (Davydov 11240), 61 (Vondrák 18130), 132 (Davydov 10858), 150 (Frolov 1589, Vondrák 18029), 157 (Vondrák 18115), 165 (Vondrák 18092), 172 (Vondrák 18231), 176 (Vondrák 18393), 177 (Vondrák 18197), 183 (Frolov 197, 206, Vondrák 18089)
Xanthocarpia ferrarii s.lat.	67 (Vondrák 18334), 169 (Vondrák 18230, 18395), 170 (Vondrák 18378), 172 (Vondrák 18195), 177 (Vondrák 18196), 181 (Vondrák 10376), 184 (Vondrák 18100), 192 (Vondrák 18379)
Xanthocarpia interfulgens	21 (Davydov 17201, 17204), 25 (Davydov 11210 & Yakovchenko, 11211 & Yakovchenko), 111 (Davydov 10861), 143 (Davydov 10305), 156 (Frolov 2034), 157 (Vondrák 18116), 158 (Vondrák 18025), 171 (Vondrák 18194, 18428), 175 (Frolov 2000, 2005, Vondrák 18261), 176 (Frolov 2055), 181 (Vondrák 10369, 10285, 10389), 183 (Frolov 196, Vondrák 18075), 185 (Vondrák 18155), 192 (Frolov 1957, Vondrák 18351, 18426), 194 (Frolov 1342, 1983, Vondrák 18298, 18349, 18439, 18444)
Xanthocarpia aff. marmorata	55 (Davydov 11239, 14146), 155 (Frolov 1802), 159 (Frolov 415, Vondrák 10411), 173 (Frolov 1886, 2019, Vondrák 18342), 175 (Frolov 1828, Vondrák 18239, 18278), 176 (Frolov 1729), 177 (Frolov 1926), 178 (Frolov 1806), 183 (Vondrák 18090), 192 (Frolov 1970, Vondrák 18365), 194 (Frolov 1335, 1347, 1355)
Xanthocarpia tominii	117 (Davydov 11197 & Yakovchenko), 118 (Davydov 11244 & Yakovchenko), 119 (Davydov 17244 & Yakovchenko), 150 (Frolov 1562, Vondrák 10311), 181 (Vondrák 10377), 185 (Vondrák 12711), 189 (Davydov 11196 & Yakovchenko, Davydov 17219 & Yakovchenko)
Xanthomendoza fulva	8 (Davydov 11359 & Zhikhareva), 38 (Davydov 10213), 42 (Davydov 10119)

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Species	Localities and vouchers
Xanthomendoza trachyphylla	181 (Frolov 139, 140), 185 (Frolov 214, Vondrák 10407, 10415, 18028), 187 (Davydov 17215)
Xanthomendoza ulophyllodes	8 (Davydov 14132 & Zhikhareva), 10 (Davydov 10806 & Zhikhareva), 13 (Davydov 39), 16 (Davydov 1854), 23 (Davydov 246), 33 (Davydov 1932), 40 (Davydov 376), 44 (Vondrák 18696), 48 (Vondrák 18051), 56 (Davydov 10869), 63 (Vondrák 18266, 18309), 65 (Vondrák 18234, 18412), 69 (Vondrák 18325, 18337), 97 (Davydov 17250), 140 (Davydov 1698), 155 (Vondrák 18250), 164 (Vondrák 18145), 165 (Vondrák 18159), 166 (Vondrák 18108), 167 (Vondrák 18148), 173 (Frolov 1788), 174 (Frolov 1706, 1744, 1750, Vondrák 18684), 176 (Vondrák 18391), 177 (Vondrák 18374), 192 (Vondrák 18346), 193 (Vondrák 18233)
Xanthoria parietina	70 (Skachko & Nozhinkov, ALTB 6001), 71 (Davydov, s.n.)