MYCOBIOLOGY
2023, VOL. 51, NO. 1, 16–25
https://doi.org/10.1080/12298093.2023.2168349

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Lecanora neobarkmaniana (Lecanorales, Lecanoraceae), A New Lichen Species from South Korea

Jung Shin Park, Sang-Kuk Han and Soon-Ok Oh

Division of Forest Biodiversity, Korea National Arboretum, Pocheon, Korea

ABSTRACT

Lecanora is one of the largest genera of lichens worldwide. These lichens can be easily seen, and are commonly found on trees and rocks. Most Korean *Lecanora* species belong to the *Lecanora subfusca* group, which has well-defined superficial thallus, red–brown apothecia, and soredia. The new species of *L. neobarkmaniana* grows on rocks, farinose soredia coalescing, usually covering the whole thallus, and containing atranorin and zeorin. We used internal transcribed spacer (ITS) and mitochondrial small subunit (mtSSU) sequence data to identify the phylogenetic relationship across *Lecanora* sequence data and found the species to form different clades. In this study, we reported some interesting findings and described the genetic relationship with other sorediate *Lecanora* species and the characteristics of the new species. An identification key for the Korean sorediate *Lecanora* species is given.

ARTICLE HISTORY
Received 22 September 2022
Revised 25 December 2022
Accepted 29 December 2022

KEYWORDS
Lichenized Ascomycota; Lecanoraceae; *Lecanora*; South Korea

1 Introduction

The genus *Lecanora* is one of the largest lichen genera and is widely distributed from the Arctic and Antarctic to subtropical regions [1]. With more than 500 species, it is the second-richest genus of lichenized fungi [2]. The genus is characterized by crustose thalli, apothecia with margins containing algal cells, and *Lecanora*-type asci with simple colorless ascospores [3]. Most Korean species belong to the *Lecanora subfusca* group, since they have soredia and the color on the disk is dark brown or black [4,5]. The *Lecanora subfusca* group is defined in this study as per Brodo [6]. *Lecanora subfusca* has a well-developed superficial thallus, and several species are characterized by the presence of soredia containing atranorin (either as a major or trace constituent), crystals in the amphithecium, and filiform conidia [6,7]. *Lecanora* having soredia, according to size it divided farinose, granular, usually covering the whole thallus or discrete thallus, while quickly spilling outwards and dispersing across the surface of the thallus [7–9]. Phylogenetic study of *Lecanora*, conducted by Zhao et al. [10], demonstrated that *Lecanora* is highly polyphyletic. The *Lecanora subfusca* group formed a sister group with the clade including *L. subcarnea* and *L. formosa*. In Malíček et al. [11], mtSSU phylogeny indicated monophyly of the *L. subfusca* group except for an unrelated species *L. cinereofusca*. However, sorediate species, such as *L. thysanophora* and *L. barkmaniana*, did not belong to the *L. subfusca* group in a narrow sense, as suggested by Aptroot and van Herk [9].

In Korea, a new *Lecanora* species were found depending on the shape of the thallus, the size of spores and hymenium, and the presence or absence of secondary metabolites such as atranorin, zeorin [4,5,12–14]. Before using DNA sequencing, it was identified preliminarily as genus *Lepraria* following morphology-based taxonomy because of sorediate thallus and containing secondary metabolites like atranorin and zeorin. It is not understandable but having a fimbriate margin and patchiness of parts if the thallus is rarely seen in those genera [15]. We first used molecular phylogenetic analysis, the new species formed a distinct clade and morphologically matched in the genus *Lecanora*. The current study aimed to present a detailed morphological, chemical, and molecular analysis of the new species using ITS and mtSSU. The updated taxonomic key prepared for the new species in Korea has been provided here.

2. Materials and methods

2.1. Specimen collection and morphological examination

The new species were collected from all over South Korea, along Gangwon-do province to Jeollanam-do province except Jeju Island (Figure 1). Most of the specimens were obtained during the survey of

CONTACT Soon-Ok Oh okkass15@korea.kr

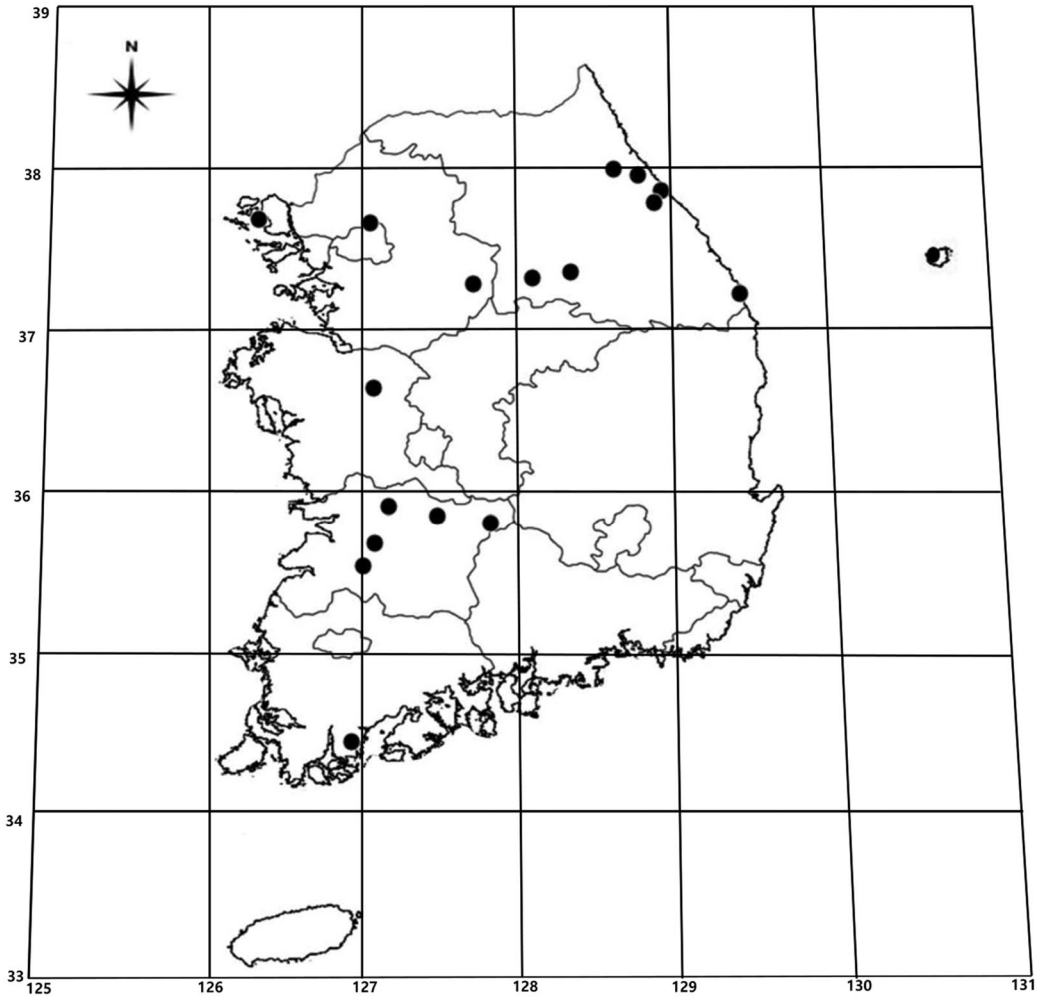

Figure 1. Collection map of *Lecanora neobarkmaniana* during 2019–2022 in South Korea. Black circles indicate the collection sites.

Korean cultural heritage sites. In order to protect cultural heritage, we collected the specimens by removing the lichen from the substrate using a bladed tool. The collected voucher specimens are deposited in the Korea National Arboretum Herbarium (KH). A stereomicroscope (Olympus SZX7; Olympus, Tokyo, Japan) was used to examine the lichen morphology, and a compound microscope (Olympus CX22LED; Olympus) was used to inspect the mycelium structure inside the thallus. In order to identify the internal substances of each lichen, 5% potassium hydroxide (K), an aqueous solution of calcium hypochlorite (C), and paraphenylenediamine (P) solutions were used to examine the color reaction (chemical color test) [16]. Chemical identification was performed by thin-layer chromatography (TLC) [16,17].

2.2. Molecular data generation, dataset assembly, and taxon sampling

DNA extraction was performed on thallus fragments using the DNeasy Plant Mini Kit (Qiagen, Valencia, CA, USA), according to the manufacturer's instructions. PCR amplifications were conducted using the AmpliTaq DNA polymerase (Thermo Fisher Scientific, Waltham, MA, USA). The following primers were used for PCR amplifications: internal transcribed spacer (ITS) for ITS4 and ITS5; mtSSU1 and mtSSU3R for mtSSU [18,19]. The following program was used for the amplification of ITS and mtSSU: initial denaturation at 95 °C for 5 min, followed by 35 cycles of 95 °C for 20 s, 55 °C for 20 s, and 72 °C for 30 s, and then a final extension step at 72 °C for 3 min. PCR program was performed using PCR premix (AccuPower PCR PreMix, BiONEER, Daejeon, Korea) according to the manufacturer's recommended protocol. The amplified DNA was concentrated and purified using a Quick-spin PCR Product Purification Kit (INTRON Biotechnology, Inc. Sungnam City, Korea) for sequencing analysis.

2.3. Sequence alignments and phylogenetic analysis

The obtained sequences were aligned with ClustalW ver. 1.83 [20] and edited using the Bioedit program

[21]. Maximum likelihood (RaxML) analyses were performed using RAxML-HPC BlackBox [22] on the Cipres Web Portal (http://www.phylo.org/sub_sections/portal) [23]. The ML search followed a GTR model of molecular evolution. Support values were obtained in RAxML with bootstrap analyses of 1000 pseudoreplicates [24]. ITS datasets were examined for the phylogenetic positions of new *Lecanora* species and one sequence (*Protoparmelia ochrococca*) was included as an outgroup [11].

3. Results and discussion

3.1. Phylogenetic analysis

We selected the *Lecanora* sequences downloaded from GenBank and newly generated sequences of the new species as well as of three reported species; collectively, there were ITS sequences from 12 samples (*L. neobarkmaniana* 6, *L. argentata* 3, *L. layana* 2, and *L. ussuriensis* 1) and mtSSU sequences from 12 samples (*L. neobarkmaniana* 6, *L. argentata* 3, *L. layana* 2, and *L. ussuriensis* 1). Nuclear ITS and mitochondrial SSU trees are presented separately owing to the gapped sequence dataset (Table 1). Our newly described species *L. neobarkmaniana* separated in *L. variolascens* and was divided by the 81% bs, and it was in a completely different clade from *L. barkmaniana* (Figure 2). mtSSU phylogeny indicated it to be more closely related to *L. variolascens* than suggested by the ITS result (Figure 3). In the mtSSU tree of a previous study, it was completely separated from the *L. subfusca* s. str. group, and *L. barkmaniana* showed a close relationship with *L. variolascens* [11]. Similar results were also confirmed in our study, and the new species was considered to have a closer relationship with *L. variolascens* (Figure 3). Brodo et al. [8] had reported *Lecanora* with sorediate thallus to belong to the *L. subfusca* group; however, there was a genetic difference unlike the previous study results [11]. In Zhao's study, *Lecanora* was defined as being highly polyphyletic, and this was confirmed in the phylogenetic tree using the 6-locus data set [10]. The new species was identified to be genetically related to *L. barkmaniana*, *L. layana*, *L. markjohnstonii*, *L. thysanophora* and *L. ussuriensis*, since it morphologically possessed soralia, and apothecia were rare or not observed. (Table 2). However, there was little difference, except for *L. barkmaniana* and *L. variolascens*. Malíček et al. [11] described the two species as identical in substance (atranorin, zeorin) and sterile, and *L. barkmaniana* having the yellow soralia became confluent. Moreover, in presence of apothecia, *L. barkmaniana* was classified as being larger in size [11]. Apothecia were not found in the new species; however, since they had the same substance (atranorin and zeorin) and soralia, they were in the same clade as *L. barkmaniana* and *L. variolascens*. Presence of atranorin, a substance common to *L. markjohnstonii* with the same substrate (saxicolous), and the absence of apothecia had greater similarities with *L. markjohnstonii*. Results from ITS and mtSSU confirmed that although *L. markjohnstonii* belongs to a clade close to a new species, the BS value was low. After the study with the addition of new sequencing results, the genetic location of *Lecanora* with sorediate lichen species can be identified and a new taxonomic study can be conducted.

3.2. Taxonomy

***Lecanora neobarkmaniana* J. S. Park & S. O. Oh, sp. nov.** (Figure. 4)

MycoBank MB845524

Similar to *Lecanora barkmaniana*, but differing in the presence of white-gray diffuse thallus with punctiform soralia (c. 0.1–0.2 mm diam.), absence of apothecia, and occurrence on rocks.

Type: South Korea, Gyeongsangbuk-do (Prov.), Ulleung-do (Island), Ulleung-gun (County), Seo-myeon, Taeha-ri, 37°30′53.89″N, 130°47′53.2″E, 132 m, on rock, May 25 2022, S. O. Oh, J. S. Park, and J. J. Seo, KL22-0032 (holotype: KHL0035552).

Etymology: The specific epithet '*neobarkmaniana*' is named after its similarity to *L. barkmaniana*.

Description: Thallus crustose, saxicolous, determinate, covering areas of up to 10 cm in diam., diffuse, dispersed to contiguous, whitish gray, rimose-verruculose, warts c. 0.1–0.2 mm diam., up to 0.1 mm thick, angular to rounded, corticate, hypothallus not observed. Soralia is always present, starting with c. 0.1–0.2 mm diam., punctiform, opening thallus warts, soon coalescing into irregular patches and usually covering most of the thallus even for a marginal zone. Soredia granular, in a dense mass, c. 15–30 µm diam., up to 30 µm thick layer, pale greenish white, concolorous with thallus. Algae cholorococcoid, globose, 20–30 µm diam. Apothecia was not observed. Pycnidia was not observed.

Chemistry: Thallus K + yellow, KC–, C–, PD + yellow; atranorin and zeorin found with TLC.

Ecology & Distribution: On rocks; from mountain to the seashore, usually on exposed rocks.

Remarks: Other species having soredia or leprose thallus similar to the new species are *L. barkmaniana*, *L. layana*, *L. markjohnstonii, L. ussuriensis, L. variolascens* and *Verseghya thysanophora*. [9,15,25,26]. Reference Table 2 shows the taxonomic characteristics distinguishing the new species from similar species. The new species was most similar to

Table 1. GenBank accession numbers and voucher information for sequenced specimens used in this paper

Taxon	Source - Specimen	GenBank Accession No.	
		ITS	mtSSU
Lecanora albella	Czech Republic, Šumava Mts, J. Malíček 7336 (hb. JM)	KY548048	KY502423
L. alboflavida	Great Britain, Scotland, B. J. Coppins s. n. (E)	KY548045	KY502427
L. allophana	Finland, Kimito, J. Malíček 9491 (hb. JM)	KY548051	KY502416
L. allophana	France, Massif Central Mts, I. Frolov & J. Vondrák (PRA)	KY548055	KY502418
L. argentata	Czech Republic, Pohorská Ves, J. Malíček 1963 (hb. JM)	KT630245	KT630264
L. argentata	Russia, Caucasus Mts, J. Malíček 9620 (hb. J. Malíček)	MK778604	MK778529
L. argentata	**South Korea, S.-O. Oh & J. S. Park KL21-0954 (KH, KHL0035558)**	**OP090557**	**OP099441**
L. argentata	**South Korea, S.-O. Oh & J. S. Park KL21-1259 (KH, KHL0035560)**	**OP090558**	**OP099442**
L. argentata	**South Korea, S.-O. Oh & J. S. Park KL21-1329 (KH, KHL0035550)**	**OP090559**	**OP099443**
L. argopholis	Austria, U. Arup L97504 (LD) n/a DQ787358	n/a	DQ787358
L. barkmaniana	Austria, Niederranna, F. Berger & J. Malíček 7352 (hb. JM)	KT630247	KT630257
L. barkmaniana	Austria, Niederranna, F. Berger & J. Malíček 7353 (hb. JM)	KT630246	KT630258
L. neobarkmaniana	**South Korea, J. S. Park & J.-J. Woo KL19-0111 (KH, KHL0031345)**	**OP090560**	**OP099444**
L. neobarkmaniana	**South Korea, S.-O. Oh & J. S. Park KL21-0848 (KH, KHL0035557)**	**OP090561**	**OP099445**
L. neobarkmaniana	**South Korea, S.-O. Oh & J. S. Park KL21-0969 (KH, KHL0035559)**	**OP090562**	**OP099446**
L. neobarkmaniana	**South Korea, S.-O. Oh & J. S. Park KL21-1293 (KH, KHL0035561)**	**OP090563**	**OP099447**
L. neobarkmaniana	**South Korea, S.-O. Oh & J. S. Park KL22-0025 (KH, KHL0035551)**	**OP090564**	**OP099448**
L. neobarkmaniana	**South Korea, S.-O. Oh & J. S. Park KL22-0032 (KH, KHL0035552)**	**OP090565**	**OP099449**
L. bicincta	Australia, Australian Capital Territory, U. Trinkaus 109 (GZU)	AY541263	n/a
L. campestris	Sweden, U. Arup (hb. Arup) [Arup & Grube 2000, Can. J. Bot.78: 318–327]	AF159930	n/a
L. campestris	Sweden, U. Arup L97370 (hb. Arup)	n/a	DQ787362
L. carpinea	Slovenia, Vojsko, J. Prügger 62808 (GZU)	AY398710	n/a
L. carpinea	Sweden, U. Arup L03192 (hb. Arup)	n/a	DQ787364
L. cateilea	Canada, British Columbia, T. Goward & J. Poelt (GZU)	AY541250	n/a
L. cenisia	Austria, Steiermark, J. Malíček 5869 (hb. JM)	KY548047	KY502425
L. cenisia	Romania, Cindrel Mts, J. Malíček 6714 (hb. JM)	KY548046	KY502426
L. cenisia 2	Czech Republic, Hrubý Jeseník Mts, J. Malíček 8702 (hb. JM)	KY548041	KY502435
L. chlarotera	Czech Republic, Sedlec-Prčice, J. Malíček 2699 (hb. JM)	n/a	KY502422
L. chlarotera	Germany, Hinterzarten, J. Malíček 5890 (hb. JM)	n/a	KT630263
L. cinereofusca	USA, North Carolina, Dare Co., J. Lendemer 34415 (NY)	KP224470	KP224465
L. cinereofusca	USA, North Carolina, Dare Co., J. Lendemer 35007 (NY)	KP224471	KP224464
L. exspersa	Slovakia, Nová Sedlica, J. Šoun & J. Vondrák 12339 (PRA)	KY548035	KY502452
L. exspersa 1	Ukraine, Ugolka, J. Malíček 8235 (hb. JM)	KY548036	KY502450
L. farinaria 2	Norway, Sogn og Fjordane, Selje, T. Tønsberg 46170 & Z. Palice (BG)	KY548043	KY502433
L. hybocarpa	Spain, Guadalajara, H. T. Lumbsch s. n. (F)	EF105412	n/a
L. hybocarpa	USA, Tennessee, F. Lutzoni et al. 03.07.04-2 (DUKE)	n/a	DQ912273
L. layana	**South Korea, S.-O. Oh & J. S. Park KL21-0165 (KH, KHL0035555)**	**OP090566**	**OP099450**
L. layana	**South Korea, S.-O. Oh & J. S. Park KL21-0502 (KH, KHL0035556)**	**OP090567**	**OP099451**
L. layana	USA, Lendemer 38131 (NY)	NR_158472	KR094858
L. impudens 1	Austria, Steiermark, J. Hafellner 76555 (GZU)	n/a	KY502454
L. impudens 2	Austria, Tirol, J. Malíček 7005 (hb. JM)	n/a	KY502453
L. intumescens	Czech Republic, Hrubý Jeseník Mts, J. Malíček 8480 (hb. JM)	KY548040	KY502441
L. intumescens	Ukraine, Ugolka, J. Malíček 8203 (hb. JM)	KY548039	KY502443
L. leptyrodes	Slovenia, Trnovski gozd, J. Prügger 65224 (GZU)	AY541255	n/a
L. markjohnstonii	USA: North Carolina	MH887500	MH221526
L. paramerae	Spain, Guadalajara, H.T. Lumbsch s. n. (F)	EF105413	n/a
L. pulicaris	Finland, Kimito, J. Malíček 9484 (hb. JM)	KY548052	n/a
L. pulicaris	Slovakia, Nová Sedlica, J. Malíček & J. Vondrák 6486 (hb. JM)	n/a	KT630262
L. pulicaris	Ukraine, Uholka, J. Vondrák s. n. (PRA)	n/a	KY502434
L. rupicola subsp sulphurata	Turkey, Prov. Izmir, H.T. Lumbsch s. n. (GZU)	AY541260	n/a
L. sorediomarginata	Portugal	GU480121	n/a
L. subcarnea	Sweden, Västergötland, U. Arup L97580 (hb. Arup)	AY541267	n/a
L. substerilis 1	Slovakia, Stužica, J. Vondrák 12294 (CBFS)	KT630243	KT630254
L. substerilis 3	Ukraine, Ugolka, J. Malíček 8209 (hb. JM)	KY548037	KY502449
L. thysanophora	Czech Republic, Šumava Mts, J. Malíček 8656 (hb. JM)	n/a	KY502440
L. thysanophora	Germany, Bayern, J. Malíček 7020 (hb. JM)	n/a	KY502444
L. thysanophora	Poland, Martin Kukwa & Ana Lubek, 17188	MN387222	n/a
L. thysanophora	Poland, Martin Kukwa & Ana Lubek, 17775	MN387223	n/a
L. ussuriensis	**South Korea, S.-O. Oh & J. S. Park KL22-0036 (KH, KHL0035553)**	**OP090568**	**OP099452**
L. variolascens	Austria, Ybbstaler Alpen Mts, J. Malíček 8422 (hb. JM)	KY548038	KY502445
Protoparmeilopsis ochrococca	USA, Oregon, B. McCune 31673 (OSU)	KP822293	KP822489

Sequences in bold are newly produced.

L. barkmaniana in its sorediate thallus; however, it differed in chemistry (e.g., atranorin), in the absence of apothecia, and in substrate preference for its rocky habitat. The new species was different from *L. layana* for not containing stictic acid and occurring in rocky conditions. *Lecanora markjohnstonii* is also a similar species, reported from the Appalachian Mountains in the United States, and is one of the *Lecanora* species without apothecia. It is corticolous and has atranorin like the new species, with the absence of zeorin and having 2-0-methylperlatolic acid. The new species is distinguished from *L. ussuriensis*'s thallus (rimose-verruculose thallus vs. bullate-areolate thallus), different chemical reaction with thallus (PD + yellow vs. thallus PD−), and the absence of apothecia. *Verseghya thysanophora* has usnic acid and the prothallus is very conspicuous and fibrous; however, the new species did not show

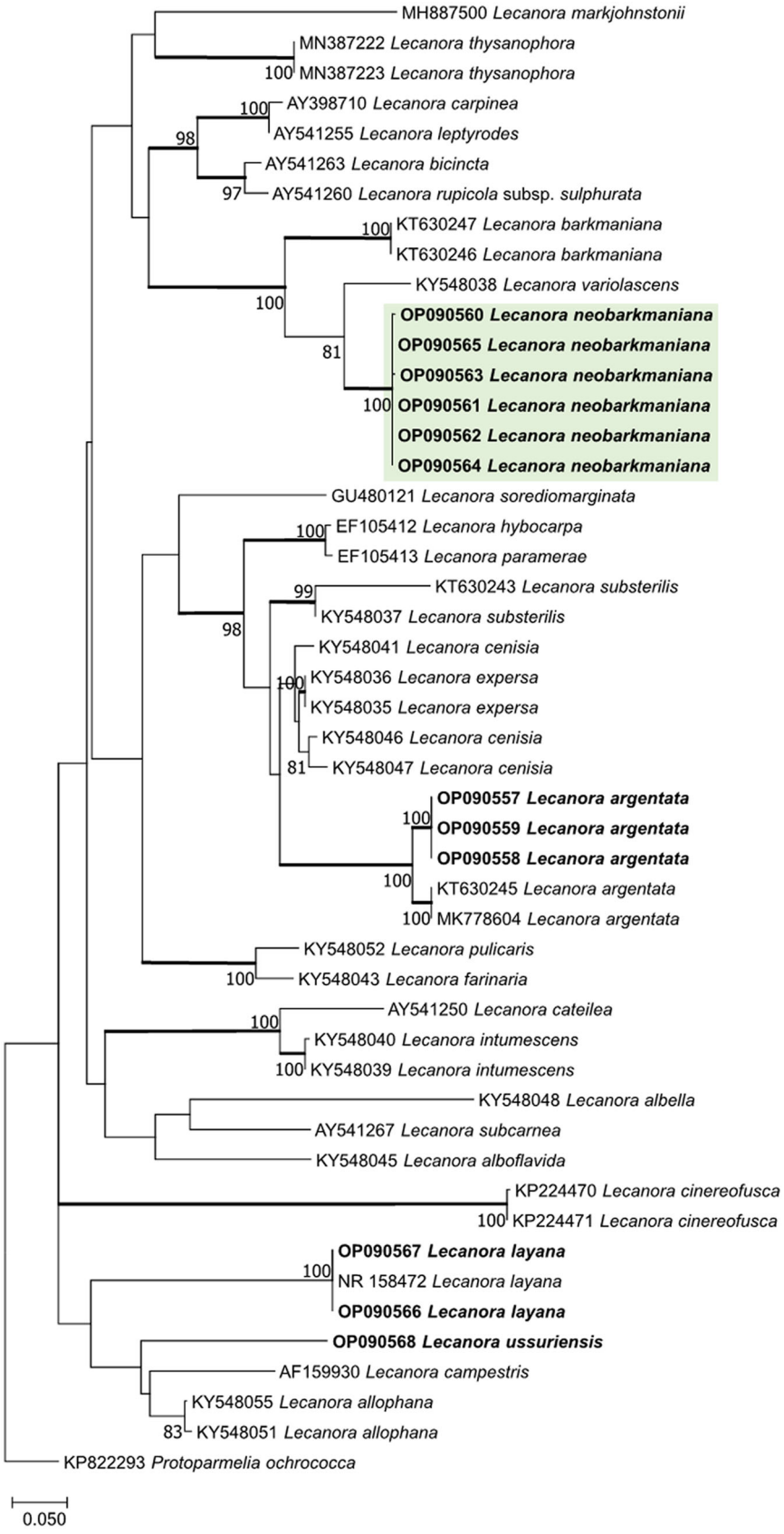

Figure 2. Maximum likelihood tree of *Lecanora* species based on ITS sequences. The ITS sequences newly generated in this study are indicated in bold. Numbers at the nodes represent the percentage of their occurrence in 1,000 bootstrap replicates. The putative new species *Lecanora neobarkmaniana* is delimited by a green box.

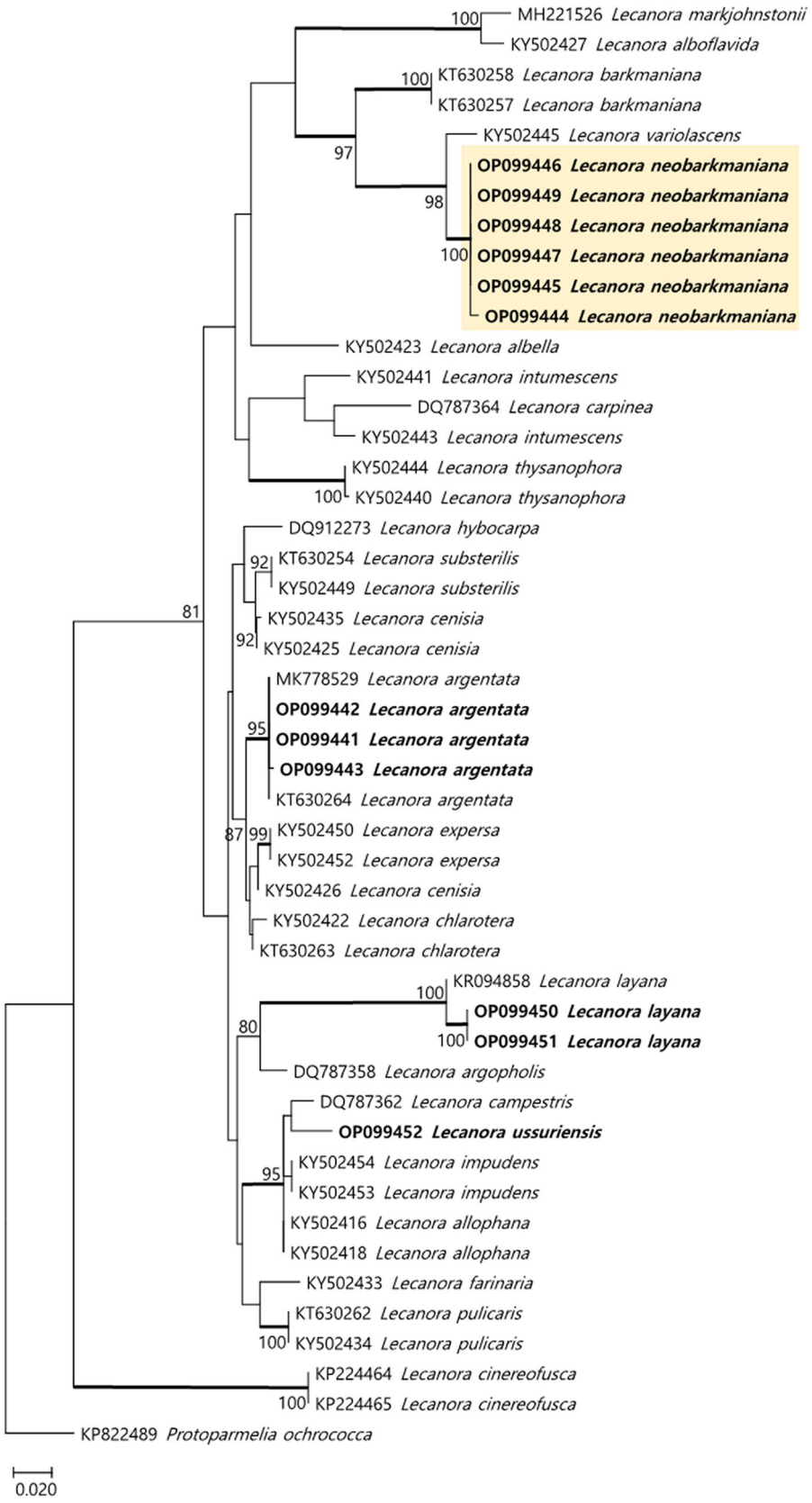

Figure 3. Maximum likelihood tree of *Lecanora* species based on mtSSU sequences. The mtSSU sequences newly generated in this study are indicated in bold. Numbers at the nodes represent the percentage of their occurrence in 1,000 bootstrap replicates. The putative new species *Lecanora neobarkmaniana* is delimited by a yellow box.

a clear prothallus. *Lecanora variolascens* resembles the new species in its chemistry (e.g., atranorin, zeorin) and soredium characteristics (e.g., flat to slightly convex). However, *L. variolascens* was distributed known only in several European countries and occurred on the bark [11]. The substrate of *Lecanora* is used as classification evidence compared to other species [6,27,28]. In particular,

Table 2. Comparison of the new species with close species in the genus *Lecanora*.

Species	*L. neobarkmaniana*	*L. barkmaniana*	*L. layana*	*L. markjohnstonii*	*L. variolascens*	*L. ussuriensis*	*Verseghya thysanophora* (=*L. thysanophora*)
Thallus form	diffuse, rimose-verruculose	determinate, covering areas of up to 5 cm diam., rimose-verruculose,	continuous	thin, poorly developed and areolate to thick, with the areoles becoming confluent and then forming a thick, continuous rimose, fissured crust	smooth to rough, often verrucose especially in the center	consisting of very convex, scattered and distant areoles	leprose, thin, continuous or patchy
prothallus/ hypothallus	Not observed	surrounded by a whitish hypothallus	conspicuous shiny film	Not observed	unknown	Not observed	conspicuous, white and fibrous, with hyphae aggregated into distinct radiating strand
Soralia	punctiform, 0.1–0.2 mm diam. opening thallus warts, soon coalescent into irregular patches	punctiform. 0-1-0-3 mm diam., opening thallus warts, soon coalescent into irregular patches	emergent, initially ± circular and regular in shape	raised, erumpent, plane, up to 1.2 mm in height, circular	flat to slightly convex, concolorous with the thallus, at first delimited (0·3–1·0 mm diam.), later more or less confluent	lateral whitish verrucae to 0.3 mm diam. (0.5–)0.7–1(–1.5) mm across or much larger confluent spots with semiconvex to convex soredious mass	forming ± continuous crust
Soreida	granular, in a dense mass, c. 15–30 μm diam.	granular, in a dense mass, c. 15–30 μm diam.	soredia fine, 14.3–40 μm in diameter	globose, fine, ca. 23–28 μm in diameter, light yellowish green and strikingly lighter than the surrounding thallus	farinose, sessile or rarely with constricted bases, plane	20–40 μm diam., usually rarely seen, mostly in consoredia to (45–)60–80(–100) μm across, not regularly rounded	developing directly from superficial prothallus, to 25 μm in diameter, often aggregated in elongate to rounded consoredia
Apothecia	absent	rare, sessile on the thallus but seemingly immersed between the soredia	unknown	not seen	frequently present	present, 0.5–1(–1.5) mm diam., highly uplifted	rarely seen, but sometimes abundant
Chemistry	atranorin and zeorin	chloratranorin and zeorin (major) and atranorin (minor)	atranorin, zeorin, and stictic acid	atranorin and 2-0-methylperlatolic acid	atranorin, chloratranorin and zeorin	unknown, spot test K + deep yellow, KC + yellow, C–, P– or weakly yellowish	atranorin, usnic acid, and zeorin
Substrate	saxicolous	corticolous	corticolous	saxicolous	corticolous	saxicolous	corticolous
Reference	Type specimens (KL22-0032) in this study.	Aptroot & van Herk 1999	Lendemer 2015	Stewart et al. 2018	Malíček et al. 2017	Kondratyuk et al. 2014	Harris et al. 2000

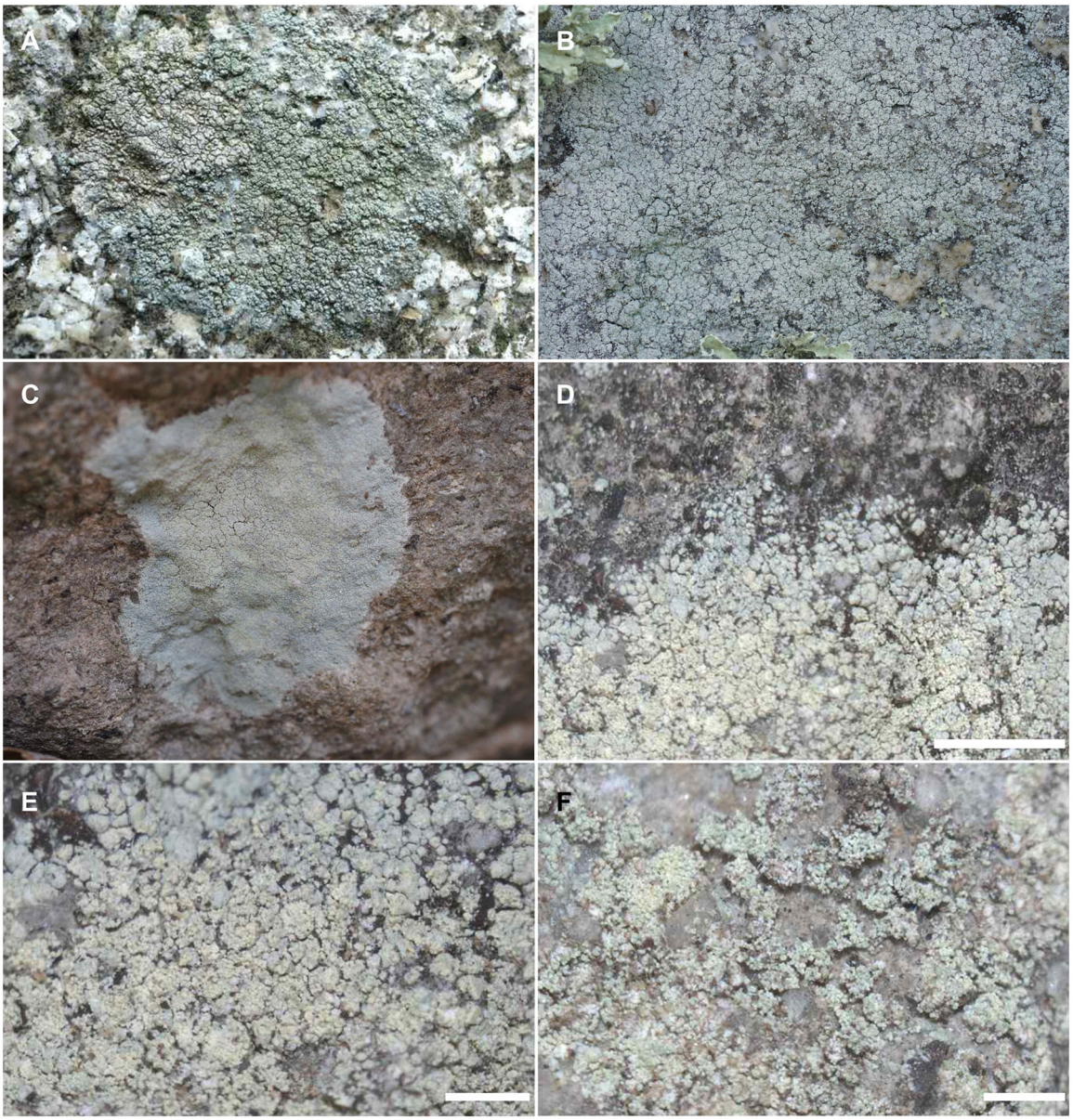

Figure 4. Habit of *Lecanora neobarkmaniana* (A) KL19-0111 (KHL0031345); (B) KL21-1293 (KHL 0035549); (C) KL22-0025 (KHL0035551); (D–F) KL22-0032 (KHL0035552, holo type); D, thallus margin; E, sorediate thallus, thallus rimose-verrucose; F, detail morphology of granular soredia. Scale bars: D = 4 mm, E–F = 0.8 mm).

Lecanora with soredia and being saxicolous are rare cases, and having no apothecia at all is very rare since this is mostly seen as corticolous (e.g., *L. barkmaniana*, *L. layana*, and *L. thysanophora*). Although *L. ussuriensis* is very rare, it is saxicolous and is related to the region where the new species was discovered. Thus, its difference with the new species can be seen clearly, since the lichen form is entirely different. Sorediate form is mostly known as the distribution form of lichens that occur in extreme conditions (freezing boreal-Arctic, alpine, and Antarctic regions to hot arid deserts) [29]. According to a study by Purvis et al. [30], reported from the UK, 90% of 1350 lichen species reproduced as apothecia, and only 29% were identified as propagule types, such as soredia [27,31]. Although the region where the new species was distributed did not have extreme conditions, most of the samples were collected from cultural heritage sites, the areas were separated from inhabited areas and were mainly isolated locations, such as mountains and marine habitats. Since the region was relatively isolated and not much developed, sorediate forms like new species could continue to grow without undergoing rapid changes in the environment, and even lichens different from those in normal temperate regions could grow.

Additional specimens examined: South Korea (County), Incheon-si (City), Kanghwa-gun, Samsan-myeon, 37°41′7.72″N, 126°19′56.44″E, 233 m, on rock, June 10 2019, J. S. Park and J. J. Woo, KL19-0111 (KHL0031345); Gangwon-do (Prov.), Gangneung-si (City), Yeongok-myeon, 37°5′25.88″N, 128°49′32.68″E, 27 m, on rock, Aug

12 2021, S. O. Oh, J. S. Park, and J. J. Seo, KL21-0969 (KHL0035547); Gangwon-do (Prov.), Yangyang-gun, Hyeonbuk-myeon, 37°56′56.72″N, 128°40′35.34″E, 221 m, on rock, Sep 11 2021, S. O. Oh, J. S. Park, and J. J. Seo, KL21-0848 (KHL0035545); same locality, 37°56′56.76″N, 128°40′35.12″E, 210 m, on rock, Sep 12 2021, S. O. Oh, J. S. Park, and J. J. Seo, KL21-1297 (KHL0035547); Gyeongsangbuk-do (Prov.), Ulleung-do (Island), Ulleung-gun, Seo-myeon, Taeha-ri, 37°30′49.62″N, 130°47′58.24″E, 125 m, on rock, May 25 2022, S. O. Oh, J. S. Park, and J. J. Seo, KL22-0025 (KHL0035551).

4. Key to sorediate *Lecanora* species of Korea

The complete Korean *Lecanora* classification key was established by Lee [5]. We made a *Lecanora* classification key for Korean sorediate *Lecanora* species with reference to the existing keys and added new and similar species (*L. markjohnstonii*, *L. neobarkmaniana*, *L. variolascens*) with new descriptions [5,11,32].

1. Thallus on rock (saxicolous)	2
1. Thallus on bark (corticolous)	5
2. Apothecia present, thallus areoles very convex	3
2. Apothecia absent or rarely seen	*L. ussuriensis*
3. Thallus flattened, rimose to irregular areoles, not convex, grayish green to whitish gray	4
3. Thallus areoles very convex, scattered and distant, dark gray	*L. ussuriensis*
4. Thallus rimose-verruculose, angular to rounded, whitish gray, contain atranorin and zeorin	***L. neobarkmaniana***
4. Thallus rimose, fissured crust, grayish green, contain atranorin and 2-0-methylperlatolic acid	*L. markjohnstonii*
5. Without apothecia	6
5. With well-developed apothecia	9
6. Arachnoid prothallus present, prothallus fibrous	*Verseghya thysanophora*
6. Arachnoid prothallus absent, prothallus not fibrous	7
7. Stictic acid present, thallus ecorticate	*L. layana*
7. Stictic acid absent, thallus corticate, rimose to verrucose	8
8. Soralia with yellow tinge, covering almost whole thallus	*L. barkmaniana*
8. Soralia white, delimited	*L. variolascens*
9. Apothecia pruinose	10
9. Apothecia not pruinose	13
10. Ascospores small, 11–14 × 6–9 µm	11
10. Ascospores large, 15–24 × 7–12 µm	12
11. Usnic acid present, soralia yellowish to bluish green, prothallus arachnoid	*V. thysanophora*
11. Usnic acid absent, soralia white to white-grey, prothallus not distinctly arachnoid	*L. variolascens*
12. Thallus white or yellowish white, asci 8- or 6-spored, ascospores 15–22 × 7–12 µm	*L. pachycheila*
12. Thallus yellowish–blue green, asci 8-spored, ascospores 15–20 × 9–12 µm	*L. sibirica*
13. Epihymenium with coarse granules (chlarotera-type)	*L. barkmaniana*
13. Epihymenium with no granule or inspersed (glabrata-type)	*L. leproplaca*

Acknowledgements

We are grateful to Ji-seon Moon, Yun-ju Jo, and Jun-yeong Kim for assistance with DNA sequencing, and to Jeong-ju Seo for help with specimen collection.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by "Distribution of Lichen on Street Trees on Selecting Bioindicators of Air Pollution" funded by the Korea National Arboretum (KNA1-1-27, 21-1).

ORCID

Jung Shin Park http://orcid.org/0000-0001-5450-7358
Sang-Kuk Han http://orcid.org/0000-0003-4549-8896

References

[1] Miyawaki H. Studies on the *Lecanora lsubfusca* group in Japan. J Hattori Bot Lab. 1988;64:271–326.
[2] Lücking R, Hodkinson BP, Leavitt SD. The 2016 classification of lichenized fungi in the Ascomycota and Basidiomycota–approaching one thousand genera. Bryologist. 2017;119(4):361–416.
[3] Ryan B, Lumbsch H, Messuti M, et al. Lichen flora of the greater sonoran desert region. Tempe: ASU; 2004.
[4] Zhang L, Wang X, Zhao Z, et al. Lichens newly recorded from the South Korean Coast. Mycotaxon. 2013;122(1):421–432.
[5] Lee B, Hur J-S. A new lichenized fungus, *Lecanora baekdudaeganensis*, from South Korea, with a taxonomic key for Korean *Lecanora* species. MycoKeys. 2020;70:39–58.
[6] Brodo I, Vanska H. Notes on the Maritime, lignicolous lichen Lecanora orae-frigidae. The Lichenologist. 1984;16(1):45–51.
[7] Lumbsch H, Messuti M, Nash T. III New or overlooked species in the *Lecanora subfusca* group from southwestern North America (Lecanorales, Ascomycotina). Bryologist. 2003;106(4):552–559.
[8] Brodo I, Owe-Larsson B, Lumbsch H. The sorediate, saxicolous species of the *Lecanora subfusca* group in Europe. Nord J Bot. 1994;14(4):451–461.
[9] Aptroot A, Van Herk C. *Lecanora Barkmaneana*, a new nitrophilous sorediate corticolous lichen from The Netherlands. Lichenologist. 1999;31(1):3–8.
[10] Zhao X, Leavitt S, Zhao Z, et al. Towards a revised generic classification of lecanoroid lichens (*Lecanoraceae*, Ascomycota) based on molecular, morphological and chemical evidence. Fungal Diversity. 2016;78(1):293–304.
[11] Malíček J, Berger F, Palice Z, et al. Corticolous sorediate *Lecanora* species (*Lecanoraceae*, Ascomycota) containing atranorin in Europe. Lichenologist. 2017;49(5):431–455.

[12] Lu L, Josh Y, Lumbsch H, et al. New and noteworthy species of the lichen genus *Lecanora* (Ascomycota; *Lecanoraceae*) from South Korea. Lichenologist. 2011;43(4):321–329.
[13] Kondratyuk S, Lőkös L, Farkas E, et al. New and noteworthy lichen-forming and lichenicolous fungi 2. Acta Bot Hung. 2015;57(1-2):108–142.
[14] Lee B, Hur J-S. Two new lecanoroid lichen species from the forested wetlands of South Korea, with a key for Korean *Protoparmeliopsis* species. MycoKeys. 2021;84:163–183.
[15] Harris R, Brodo I, Tønsberg T. *Lecanora thysanophora*, a common leprose lichen in Eastern North America. Bryologist. 2000;103(4):790–793.
[16] Orange A, James PW, White F. Microchemical methods for the identification of lichens. London, UK: British Lichen Society; 2001.
[17] Elix J. A catalogue of standardized chromatographic data and biosynthetic relationships for lichen substances. Canberra. 2014. p. 1–323.
[18] White T, Bruns T, Lee S, et al. Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics: PCR protocols: a guide to methods and applications1990. 315–22 p.
[19] Zoller S, Scheidegger C, Sperisen C. PCR primers for the amplification of mitochondrial small subunit ribosomal DNA of lichen-forming ascomycetes. Lichenologist. 1999;31(5):511–516.
[20] Thompson J, Higgins D, Gibson T. CLUSTAL W: improving the sensitivity of progressive multiple sequence alignment through sequence weighting, position-specific gap penalties and weight matrix choice. Nucleic Acids Res. 1994; 22(22):4673–4680.
[21] Hall T, Editor BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucleic acids symposium series.; 1999. [London]: Information Retrieval Ltd., c1979–c2000.
[22] Stamatakis A. RAxML version 8: a tool for phylogenetic analysis and post-analysis of large phylogenies. Bioinformatics. 2014;30(9):1312–1313.
[23] Miller MA, Pfeiffer WTS. Creating the CIPRES science gateway for inference of large phylogenetic trees. 2010 Gateway Computing Environments Workshop (GCE); New Orleans, LA; 2010. p. 1–8.
[24] Miller M, Pfeiffer W, Schwartz T. Creating the CIPRES science gateway for inference of large phylogenetic trees. Gateway Computing Environments Workshop (GCE). New Orleans, LA: IEEE; 2010. p. 1–8.
[25] Kondratyuk S, Lőkös L, Tschabanenko S, et al. *Caloplaca kedrovopadensis* sp. nova and some new lichens from the Primorsky region, Russia. Acta Botanica Hungarica. 2014;56(1–2):125–140.
[26] Lendemer J. *Lecanora layana* (*Lecanoraceae*), a new sorediate species widespread in temperate Eastern North America. Bryologist. 2015;118(2): 145–153.
[27] Smith C, Aptroot B, Coppins B, et al. Lichens of Great Britain and Ireland. 2nd ed. London: BLS; 2009. 1046. p.
[28] Tripp E, Morse C, Keepers K, et al. Evidence of substrate endemism of lichens on fox hills sandstone: discovery and description of *Lecanora lendemeri* as new to science. Bryologist. 2019;122(2):246–259.
[29] Purvis W. Lichens. London: Natural history museum; 2000.
[30] Purvis O, Coppins B, Hawksworth D, et al. The lichen flora of Great Britain and Ireland. London: Natural History Museum; 1992.
[31] Seymour F, Crittenden P, Dyer P. Sex in the extremes: lichen-forming fungi. Mycologist. 2005; 19(2):51–58.
[32] Papong K, Lumbsch H. A taxonomic survey of *Lecanora* sensu stricto in Thailand (*Lecanoraceae*; Ascomycota). Lichenologist. 2011; 43(4):299–320.