Two new calcicolous caloplacoid lichens from South Korea, with a taxonomic key to the species of *Huriella* and *Squamulea*

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Abstract

*Pyrenodesmia rugosa* Lee & Hur and *Huriella aeruginosa* Lee & Hur are described as new lichen-forming fungi from a calcareous mountain of South Korea. *Pyrenodesmia rugosa* is distinguishable from *Pyrenodesmia micromontana* (Frolov, Wilk & Vondrák) Hafellner & Türk, the most similar species, by thicker thallus, rugose areoles, larger apothecia, shorter hymenium, shorter hypothecium and narrower tip cells of paraphyses. *Huriella aeruginosa*, the second new species, differs from *Squamulea chelonia* Bungartz & Sochting by dark greenish-grey to grey thallus without pruina, gold to yellow-brown epihymenium, larger ascospores and thallus K– and KC– reaction. Molecular analyses employing internal transcribed spacer (ITS), mitochondrial small subunit (mtSSU) and nuclear large subunit ribosomal RNA (LSU) sequences strongly support the two caloplacoid species to be distinct in their genera. A surrogate key is provided to assist in the identification of all 20 taxa in *Huriella* and *Squamulea*.

Keywords

Biodiversity, phylogeny, saxicolous, taxonomy, Teloschistaceae
Introduction

Many lichens are only detected in calcareous areas, particularly for crustaceous lichens, as many plants are never found, except on calcareous rocks and soils (Watson 1918; Kossowska 2008; Pykälä et al. 2017). Caloplacoid lichens have been discovered in calcareous areas, such as *Pyrenodesmia albobustulata* (Khodos. & S.Y. Kondr.) I.V. Frolov & Vondrák, *P. badioreagens* (Tietjach & Muggia) Sochting, Arup & Frödén, *P. concreticola* (Vondrák & Khodos.) Sochting, Arup & Frödén, *P. erodens* (Tietjach, Pinna & Grube) Sochting, Arup & Frödén, ‘*Squamulea* chelonia, *Squamulea galactophylla* (Tuck.) Arup, Sochting & Frödén, ‘*Squamulea* humboldtiana’ Bungartz & Sochting, *Squamulea parviloba* (Wetmore) Arup, Sochting & Frödén and *S. subsoluta* (Nyl.) Arup, Sochting & Frödén (Khodosovtsev et al. 2002; Tietjach et al. 2003; Wetmore 2003; Tietjach and Muggia 2006; Vondrák 2008; Arup 2013; Bungartz et al. 2020). Many lichens have been introduced from the calcareous areas in Korea, such as *Anema decipiens* (A. Massal.) Forssell, *Astroplaca loekoesiana* S.Y. Kondr., Farkas, J.J. Woo & Hur, *Caeruleum heppii* (Nägeli ex Körb.) K. Knudsen & Arcadia, *Clauzadea metzleri* (Körb.) Clauzade & Cl. Roux, *Clauzadea monticola* (Ach.) Hafellner & Bellem., *Collema auriforme* (With.) Coppins & J.R. Laundon, *Cristatula* (L.) Weber ex F.H. Wigg., *Endocarpon pallidum* Ach., *Halecania pakistanica* van den Boom & Elix, *Heppia adglutinata* A. Massal., *Ionaspis epulotica* (Ach.) Blomb. & Forssell, *Lecania turicensis* (Hepp) Müll. Arg., *Lecanora albescens* (Hoffm.) Branth & Rostr., *L. semipallida* H. Magn., *Lemmopsis arnoldiana* (Hepp) Zahlbr., *Lichinella cribellifera* (Nyl.) P.P. Moreno & Egea, *L. stipatula*Nyl., *Placynthium tantaleum* (Hepp) Hue, *Porina fluminea* P.M. McCarthy & P.N. Johnson, *Psorotichia frustulosa* Anzi, *P. schaereri* (A. Massal.) Arnold, *Pterygiopsis affinis* (A. Massal.) Henssen, *Pyrenocarpon aff. thelostomum* (Ach. ex J. Harriman) Coppins & Aptroot, *Rufoplaca aesanensis* S.Y. Kondr. & Hur, *Staurothele frustulenta* Vain., *Synalissa ramulosa* (Hoffm.) Körb., *Thyrea confusa* Henssen, *Toniinia poeltiana* S.Y. Kondr., Lökös & Hur, *T. tristis* (Th. Fr.) Th. Fr. and *Verrucaria muralis* Ach. (van den Boom and Elix 2005; Joshi et al. 2009; Schultz and Moon 2011; Aptroot and Moon 2014, 2015, Kondratyuk et al. 2016a, 2016b, 2017a, 2020). Although calcicolous caloplacoid lichens were little reported from Korea in the past, for example, *Rufoplaca aesanensis*, it is assumed that diverse caloplacoid lichens inhabit calcareous rocks and soils which were previously reported from just rock or soil without specifying specific rock or soil types.

This study describes two new calcicolous caloplacoid lichens in the genera *Pyrenodesmia* and *Huriella*. Qualified field surveys for the lichen diversity on the Baekdudaegan Mountains, the main mountain range stretching across the entire Korean Peninsula, were accomplished during the summer of 2020 and a few dozen specimens of caloplacoid lichens were collected in Mt. Seokbyung, a calcareous mountain (Fig. 1). We describe them as two new species, *Pyrenodesmia rugosa* and *Huriella aeruginosa*. The specimens are deposited in the herbarium of the Baekdudaegan National Arboretum (KBA), South Korea.
Materials and methods

Morphological and chemical analyses

Hand-cut sections were prepared with a razor blade under a stereomicroscope (Olympus optical SZ51; Olympus, Tokyo, Japan), examined under a compound microscope (Nikon Eclipse E400; Nikon, Tokyo, Japan) and imaged using a software programme (NIS-Elements D; Nikon, Tokyo, Japan) and a DS-Fi3 camera (Nikon, Tokyo, Japan), mounted on a Nikon Eclipse Ni-U microscope (Nikon, Tokyo, Japan). The ascospores were investigated at 1000× magnification in water. The length and width of the ascospores were measured and the range of spore sizes was shown with average, standard deviation and number of measured spores. Thin-layer chromatography (TLC) was performed using solvent systems A and C according to standard methods (Orange et al. 2001).

Isolation, DNA extraction, amplification and sequencing

Hand-cut sections of ascomata or thallus from all collected specimens were prepared for DNA isolation and DNA was extracted with a NucleoSpin Plant II Kit in line with the manufacturer’s instructions (Macherey-Nagel, Düren, Germany). PCR amplification for the internal transcribed spacer region (ITS1-5.8S-ITS2 rDNA), the mitochondrial
small subunit and the nuclear large subunit ribosomal RNA genes was achieved using Bioneer’s AccuPower PCR Premix (Bioneer, Daejeon, Korea) in 20-µl tubes and primers ITS5 and ITS4 (White et al. 1990), mrSSU1 and mrSSU3R (Zoller et al. 1999) and LR0R and LR5 (Rehner and Samuels 1994), respectively. The PCR thermal cycling parameters used were 95 °C (15 sec), followed by 35 cycles of 95 °C (45 sec), 54 °C (45 sec) and 72 °C (1 min) and a final extension at 72 °C (7 min), based on Ekman (2001). DNA sequences were generated by the genomic research company Macrogen (Seoul, Korea).

### Phylogenetic analyses

All ITS, mtSSU and LSU sequences were aligned and edited manually using ClustalW in Bioedit V.7.2.6.1 (Hall 1999). All missing and ambiguously aligned data and parsimony-uninformative positions were removed and only parsimony-informative regions were finally analysed in MEGA X (Stecher et al. 2020). The final alignment comprised 878 (ITS), 900 (mtSSU) and 1701 (LSU) columns for *Pyrenodesmia*. In them, variable regions were 178 (ITS), 42 (mtSSU) and 618 (LSU). The phylogenetically-informative regions were 356 (ITS), 55 (mtSSU) and 98 (LSU). The final alignment for *Huriella* and *Squamulea* comprised 693 (ITS) columns. In them, variable regions were 78 (ITS). Finally, the phylogenetically-informative region was 246 (ITS). Phylogenetic trees with bootstrap values were obtained in RAxML GUI 2.0 beta (Edler et al. 2019) using the Maximum Likelihood method with a rapid bootstrap with 1000 bootstrap replications and GTR GAMMA for the substitution matrix. The posterior probabilities were obtained in BEAST 2.6.4 (Bouckaert et al. 2019) using the HKY (Hasegawa, Kishino and Yano) model, as the appropriate model for nucleotide substitution, based on the Bayesian Information Criterion (BIC) (Schwarz 1978) as evaluated by bModelTest (Bouckaert and Drummond 2017), empirical base frequencies, gamma for the site heterogeneity model, four categories for gamma and a 10,000,000 Markov Chain Monte Carlo chain length with a 10,000-echo state screening and 1000 log parameters. Then, a consensus tree was constructed in TreeAnnotator 2.6.4 (Bouckaert et al. 2019) with a burn-in of 5000, no posterior probability limit, a maximum clade credibility tree for the target tree type and median node heights. All trees were displayed in FigTree 1.4.2 (Rambaut 2014) and edited in Microsoft Paint. The bootstrapping and Bayesian analyses were repeated three times for the result consistency and no significant differences were shown for the tree shapes and branch values. The phylogenetic trees and DNA sequence alignments are deposited in TreeBASE under the study ID 28190.

### Results and discussion

#### Phylogenetic analyses

Three independent phylogenetic trees for *Pyrenodesmia* and one independent phylogenetic tree for *Squamulea* were produced from 165 sequences (96 for ITS, 37 for mtSSU and 32 for LSU) from GenBank and four new sequences (two for ITS, one for mtSSU...
and one for LSU) for the new species (Table 1). *Pyrenodesmia rugosa*, a new species, was positioned in the genus *Pyrenodesmia* in all ITS, mtSSU and LSU trees. The ITS tree described that the new species was solely located without any clade. Several species closely positioned with the new species were *Pyrenodesmia aractina* (Fr.) S.Y. Kondr., *P. bicolor* (H. Magn.) S.Y. Kondr. and *P. haematites* (Chaub. ex St.-Amans) S.Y. Kondr., represented by a bootstrap value of 84 and a posterior probability of 0.73 (not shown) for the branch (Fig. 2). The mtSSU tree showed that the new species was located in a clade with *Pyrenodesmia albopruinosa* (Arnold) S.Y. Kondr. and *P. micromontana*, represented by a bootstrap value of 72 and a posterior probability of 1.0 for the branch (Fig. 3). The LSU tree depicted that the new species was positioned solely without any clade. Several species, such as *Kuettlingeria cretensis* (Zahlbr.) I.V. Frolov & Vondrák, *K. neotaurica* (Vondrák, Khodos., Arup & Søchting) I.V. Frolov, Vondrák & Arup, *Pyrenodesmia albopustulata*, *P. chalybaea* (Fr.) A. Massal., *P. helgeoides* (Vain.) Arnold, *P. microstepposa* (Frolov, Nadyeina, Khodos. & Vondrák) Hafellner & Türk, *P. molariformis* (Frolov, Vondrák, Nadyeina & Khodos.) S.Y. Kondr., *P. pratensis* (Wetmore) Frolov & Vondrák and *P. variabilis* (Pers.) A. Massal. are situated close to the new species (Fig. 4).

*Huriella aeruginosa*, the second new species, was located in *Huriella* in the ITS tree. The ITS tree described that the new species was positioned in a clade with ‘*Squamulea* subsoluta’ and ‘*Squamulea*’ sp., represented by a bootstrap value of 35 (not shown) without a posterior probability as the Maximum Likelihood analysis did not match with the Bayesian Inference for the clade (Fig. 5). Although the two closely located sequences were named for *Squamulea* in the beginning, they are close to *Huriella*, not *Squamulea*. The two sequences are arranged in the genus *Huriella* with the new species. The phylogenetic analyses did not designate any species identical to the two new species in each genus *Pyrenodesmia* and *Huriella*.

**Taxonomy**

*Pyrenodesmia rugosa* B.G. Lee & J.-S. Hur, sp. nov.

MycoBank No: 839184

Fig. 6

**Diagnosis.** *Pyrenodesmia rugosa* differs from *P. micromontana* by thicker thallus (125–200 μm vs. 95–125 μm), rugose areoles (vs. flat areoles), larger apothecia (0.2–0.7 mm diam. vs. 0.2–0.4 mm diam.), shorter hymenium (60–70 μm vs. 80–100 μm), shorter hypothecium (50–55 μm vs. 80–100 μm) and narrower tip cells of paraphyses (3–4.5 μm vs. 5–6 μm).

**Type.** South Korea, Gangwon Province, Gangneung, Okgye-myeon, Mt. Seokbyung (summit), 37°35.21’N, 128°53.87’E, 1,072 m alt., on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000902, with *Athallia* cf. *vitellinula* (Nyl.) Arup, Frödén & Søchting, *Bagliettoa baldensis* (A. Massal.) Vězda, *Catillaria lenticularis* (Ach.) Th. Fr. and *Staurothele* aff. *succedens* (Rehm) Arnold (holotype: BDNA-L-0001102!); same locality, on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000899, with *Athallia* cf. *holocarpa* (Hoffm.) Arup, Frödén & Søchting and *Staurothele* cf. *rupifraga*
### Table 1. Species list and DNA sequence information employed for phylogenetic analysis.

| No | Species                  | ID (ITS) | ID (mtSSU) | ID (LSU) | Voucher          |
|----|--------------------------|----------|------------|----------|------------------|
| 1  | Amundsenia approximata   | KJ789965 | L08179     |          | (LD)             |
| 2  | Amundsenia australis      | KJ789962 | 21966      |          | (HO)             |
| 3  | Athallia holocarpa        | MG954144 | Vondrak 18072 |        |                  |
| 4  | Athallia vitellinulina    | FJ346556 | Arup L03052 |        |                  |
| 5  | Caloplaca monacensis      | MG773668 | Malicke 8255 |        |                  |
| 6  | Caloplaca sp.             | KC611244 | CBFS:JV6943 |        |                  |
| 7  | Erichansenia sauronii     | KC179120 | Sochting 7654 |        |                  |
| 8  | Huriella aeruginosa       | MW832829 | BDNA-L-0001072 |        |                  |
| 9  | Huriella flakusii         | MT967442 | Bungartz 4131 | (CDS 28162) |                  |
| 10 | Huriella flakusii         | MT967444 | Bungartz 4157 | (CDS 28188) |                  |
| 11 | Huriella loekoesiana      | KY614406 | KoLRI 15423 |        |                  |
| 12 | Huriella loekoesiana      | KY614407 | KoLRI 19017 |        |                  |
| 13 | Huriella loekoesiana      | KY614408 | KoLRI 40141 |        |                  |
| 14 | Huriella loekoesiana      | KY614409 | KoLRI 40236 |        |                  |
| 15 | Huriella loekoesiana      | KY614410 | KoLRI 40238 |        |                  |
| 16 | Huriella loekoesiana      | KY614411 | HKAS 102112 |        |                  |
| 17 | Huriella loekoesiana      | KY614412 | KRAM-L-70242 |        |                  |
| 18 | Huriella loekoesiana      | KY614413 |                 |        |                  |
| 19 | Kuettlingeria albolutea   | KC179423 | Arup L09030 | (LD)    |                  |
| 20 | Kuettlingeria areolata    | MN305805 | Vondrak 10854 |        |                  |
| 21 | Kuettlingeria atroflava   | MH104921 | Vondrak 8723 | (PRA)  |                  |
| 22 | Kuettlingeria cretensis   | MH104925 | Frolov s.n. |        |                  |
| 23 | Kuettlingeria diphyodes   | MH104926 | Frolov 1430 |        |                  |
| 24 | Kuettlingeria emilii      | KC416102 | JV9358      |        |                  |
| 25 | Kuettlingeria eurybrocarpa | KC179427 | Arup L07109 | (LD)    |                  |
| 26 | Kuettlingeria neotaurica  | MN305807 | Vondrak 7213 |        |                  |
| 27 | Kuettlingeria percrocata  | MH104931 | Vondrak 4634 | (PRA)  |                  |
| 28 | Kuettlingeria soralifera  | MN305808 | Vondrak 10813 |        |                  |
| 29 | Kuettlingeria aff. soralifera | JN641781 | CBFS:JV8325 |        |                  |
| 30 | Kuettlingeria teicholyta  | MH104935 | Vondrak 6943 | (PRA)  |                  |
| 31 | Kuettlingeria xerica      | MN305809 | Vondrak 14544 |        |                  |
| 32 | Kuettlingeria aff. xerica | H6Q11275 | CBFS:JV7618 |        |                  |
| 33 | Lendemeriella borealis   | MG954129 | Vondrak 11073 |        |                  |
| 34 | Lendemeriella executa    | MG954227 | Spribille 24441 |        |                  |
| 35 | Lendemeriella nivalis    | MG954222 | Spribille 29306 |        |                  |
| 36 | Lendemeriella reptans    | MH104934 | Lendemer 48186 | (NY)  |                  |
| 37 | Lendemeriella sorocarpa  | MG954132 | Vondrak 12695 |        |                  |
| 38 | Lendemeriella tormoearpa | MG954221 | Spribille 29473 |        |                  |
| 39 | Oleghinia demissa         | KT220203 | X. Llimona (BCN) |        |                  |
| 40 | Pyrenodesmia aetnensis    | EU639590 | TSB 37658 |        |                  |
| 41 | Pyrenodesmia alboperinaea | EF093577 | GT91476 |        |                  |
| 42 | Pyrenodesmia alboperinata | MH104918 | Vondrak 10463 | (PRA)  |                  |
| 43 | Pyrenodesmia alociza      | EF090931 | TSB 37735 |        |                  |
| 44 | Pyrenodesmia aractina     | GU723415 | Bornholm 5907 |        |                  |
| 45 | Pyrenodesmia aractina     | GU723418 | Bornholm 6911 |        |                  |
| 46 | Pyrenodesmia aractina     | MH104919 | Vondrak 6702 | (PRA)  |                  |
| 47 | Pyrenodesmia aractina     | MH104920 | X. Llimona (BCN) |        |                  |
| 48 | Pyrenodesmia badioretans  | EF081035 | TSB 36422 |        |                  |
| 49 | Pyrenodesmia bicolor      | MH104922 | Vondrak 10373 | (PRA)  |                  |
| No | Species                  | ID (ITS) | ID (mtSSU) | ID (LSU) | Voucher               |
|----|--------------------------|----------|------------|----------|-----------------------|
|   | Pyrenodesmia ceracea     | HQ234603 | MH100779   | MH100747 | BM-6656               |
| 50 | Pyrenodesmia chalybaea    | KC884498 | MH100780   | MH100748 | CBFS;JV4059           |
| 51 | Pyrenodesmia circumalbata | MH104923 | MH100781   | MH100749 | Halici s.n.           |
| 52 | Pyrenodesmia concreticola | KC884506 | MH100781   | MH100749 | CBFS;JV9443           |
| 53 | Pyrenodesmia duplicata    | HQ611272 |            |          | TUR-V-7513            |
| 54 | Pyrenodesmia erodens      | MH104927 | MH100788   | MH100755 | Vondrak 12733 (PRA)   |
| 55 | Pyrenodesmia haematites   | GU723420 | MH100789   | MH100756 | Vondrak 7278 (PRA)    |
| 56 | Pyrenodesmia haematites   | GU723421 |            |          | JS280                 |
| 57 | Pyrenodesmia helygeoides  | MH104928 |            |          | Vondrak 7278 (PRA)    |
| 58 | Pyrenodesmia helygeoides  | MH104929 | MH100790   | MH100757 | Frolov 1414           |
| 59 | Pyrenodesmia micromarina  | NR_156257| MH100791   | MH100758 | CBFS;JV8199           |
| 60 | Pyrenodesmia micromarina  | MH100791 | MH100758   |          | Vondrak 7236 (PRA)    |
| 61 | Pyrenodesmia micromontana | NR_158297| MH100792   | MH100759 | CBFS;JV9467           |
| 62 | Pyrenodesmia microstepposa| NR_156260| MH100760   | MH100760 | CBFS;JV9141           |
| 63 | Pyrenodesmia molariformis | KC416145 | MH100793   | MH100761 | Nadyeina 132 (KW)     |
| 64 | Pyrenodesmia obscurella   | MH104938 | MH100762   | MH100762 | Vondrak 7641 (PRA)    |
| 65 | Pyrenodesmia peliophylla  | MG733135 |            |          | Jason Hollinger:16476 |
| 66 | Pyrenodesmia pratensis    | MH104933 | MH100795   | MH100765 | MIN 891605            |
| 67 | Pyrenodesmia rugosa       | MW832828 | MW832825   | MW832904 | BDNA-L-0001099        |
| 68 | Pyrenodesmia transcarpica | MH104936 | MH100799   | MH100768 | Vondrak 9430 (PRA)    |
| 69 | Pyrenodesmia variabilis   | KT291466 | KT291514   | KT291561 | Ulf Arup L07196 (LD)  |
| 70 | Shackletonia buelliae     | KC179117 |            |          | Sochting 7583         |
| 71 | Shackletonia siphonopora  | KC179121 |            |          | Sochting 7883         |
| 72 | Squamulea galactophylla   | KC179122 |            |          | Morse 10997 (LD)      |
| 73 | Squamulea kiamae          | KC179123 |            |          | Kondratyuk 20480 (LD) |
| 74 | Squamulea parviflora      | KC179124 |            |          | Wetmore 87830 (LD)    |
| 75 | Squamulea squamosa        | MT967462 |            |          | Moberg 8782 (UPS)     |
| 76 | Squamulea squamosa        | KC179125 |            |          | Karnefelt AM9060105 (LD) |
| 77 | Squamulea ‘squamosa’      | MT967465 |            |          | Bungartz 7428 (CDS 37915) |
| 78 | Squamulea subsoluta       | AF353954 |            |          | Arup L97072           |
| 79 | Squamulea subsoluta       | DQ173238 |            |          | Arup L97829           |
| 80 | Squamulea subsoluta       | KJ133480 |            |          | KoLRI 011067          |
| 81 | Squamulea ‘chelonia’      | MT967448 |            |          | Bungartz 4521 (CDS 28607) |
| 82 | Squamulea ‘chelonia’      | MT967451 |            |          | Bungartz 9251 (CDS 46069) |
| 83 | Squamulea ‘chelonia’      | MT967452 |            |          | Bungartz 6146 (CDS 34358) |
| 84 | Squamulea ‘chelonia’      | MT967439 |            |          | Buck 29560 (MIN)      |
| 85 | Squamulea ‘humboldtiana’  | MT967440 |            |          | Bungartz 4711B (CDS 56235) |
| 86 | Squamulea ‘humboldtiana’  | MT967441 |            |          | Bungartz 9985 (CDS 47354) |
| 87 | Squamulea ‘humboldtiana’  | MT967445 |            |          | Yánez-Ayabaca 2023 (CDS 48373) |
| 88 | Squamulea ‘oceanica’      | MT967446 |            |          | Bungartz 10152 (CDS 47571) |
| 89 | Squamulea ‘oceanica’      | MT967447 |            |          | Bungartz 9857 (CDS 47195) |
| 90 | Squamulea ‘oceanica’      | MT967455 |            |          | AptoHo 65489 (CDS 32078) |
| 91 | Squamulea ‘osseophila’    | MT967456 |            |          | AptoHo 65468 (CDS 32057) |
| 92 | Squamulea ‘phyllidizans’  | MT967456 |            |          |                     |
Beeyoung Gun Lee & Jae-Seoun Hur  /  MycoKeys 84: 35–55 (2021)

(A. Massal.) Arnold (paratype: BDNA-L-0001099; GenBank MW832828 for ITS, MW832825 for mtSSU and MW832804 for LSU).

Thallus saxicolous (calcicolous), crustose, mainly areolate or slightly rimose, rugose, greyish-brown to pale brown, often with orange spots, margin indeterminate or determinate when placodioid areoles are arranged around edge, vegetative propagules absent, areoles 0.4–1.0 mm diam., 125–200 μm thick; cortex hyaline with pale brown pigment layer, pale brown pigment K+ purple, 10–40 μm thick, cortical cells granular, 5–10 μm diam., with epinecral layer, 5–7 μm thick; medulla 60–110 μm thick below algal layer or inconspicuous and algal layer shown just above substrate; photobiont coccoid, cells globose to oval, 5–15 μm diam., algal layer 50–70 μm thick. Small crystals present between algal cells, not dissolving in K. Prothallus absent.

Apothecia abundant, scattered or concentrated in centre, rounded, often contiguously or even coalescent when mature, emerging on the surface of thallus, immersed or adnate, slightly constricted at the base, 0.2–0.7 mm diam. Disc flat when young and flat or concave when mature, often white pruinose, black, 200–300 μm thick; zeorine, margin persistent, generally entire or rarely slightly crenulate, thalline margin paler to disc and showing brown colour, often inconspicuous due to locating below proper margin, proper margin concolorous to disc. Amphithecium present, with small crystals between algal cells, not dissolving in K, 80–130 μm wide laterally, algal layers continuous to the base and underlying the hypothecium, algal cells 5–15 μm diam., cortical layer hyaline with pale brownish pigment at periphery, 10–40 μm thick. Parathecium well-developed, hyaline, but grey with slightly brown pigment concolorous to ephymenium at periphery, 20–40 μm wide laterally and 50–90 μm wide at periphery. Ephymenium grey with slightly brown pigment, K+ purple, tiny granules abundant on surface, not dissolving in K, 5–10 μm high. Hymenium hyaline, 60–70 μm high. Hypothecium hyaline, base open and extending downwards, 50–55 μm high. Oil droplets present in upper hypothecium, but absent in hymenium. Paraphyses septate, often anastomosing, 2–2.5 μm wide, generally simple, but occasionally branched at tips, tips slightly swollen, not pigmented, 3.0–4.5 μm wide. Asci oblong to narrowly clavate, 8-spored, 52–60 × 14–18 μm (n = 5). Ascospores ellipsoid, 1-septate, polarilocular when mature or narrow septum remaining, hyaline
Korean calcicolous caloplacoid lichens

permanently, 11–18 × 5.5–11 μm (mean = 14.1 × 7.6 μm; SD = 1.6(L), 1.0(W); L/W ratio 1.5–2.5, ratio mean = 1.9, ratio SD = 0.3; n = 105), septum 1.5–3.0 μm. Pycnidia not detected.

**Chemistry.** Thallus K–, KC–, C–, Pd–. Epihymenium K+ purple. Hymenium I+ blue. UV–. No lichen substance was detected by TLC.

**Figure 2.** Phylogenetic relationships amongst available species in the genus *Pyrenodesmia*, based on a Maximum Likelihood analysis of the dataset of ITS sequences. The tree was rooted with the sequences of the genera *Caloplaca*, *Lendemeriella*, *Olegblumia* and *Usnochroma*. Maximum Likelihood bootstrap values ≥ 70% and posterior probabilities ≥ 95% are shown above internal branches. Branches with bootstrap values ≥ 90% are shown in bold. The new species *Pyrenodesmia rugosa* is presented in bold and all species names are followed by the GenBank accession numbers. Reference Table 1 provides the species related to the specific GenBank accession numbers and voucher information.
Distribution and ecology. The species occurs on the calcareous rock. The species is currently known from the type collections.

Etymology. The species epithet indicates the lichen’s thallus texture, rugose or wrinkled, which is the key characteristic distinguished from closely-related calcicolous species in the genus *Pyrenodesmia*.

Notes. The new species is similar to *P. micromontana*, *P. microstepposa* and *Caloplaca micromarina* Frolov, Khodos. & Vondrák in having epilithic thallus without vegetative propagules, small apothecia generally less than 0.5 mm diameter and the substrate preference to calcareous rocks. The new species differs from *P. micromontana* by thicker thallus (125–200 μm vs. 95–125 μm), rugose areoles (vs. flat areoles), larger apothecia (0.2–0.7 mm diam. vs. 0.2–0.4 mm diam.), shorter hymenium (60–70 μm vs. 80–100 μm), shorter hypothecium (50–55 μm vs. 80–100 μm) and narrower tip cells of paraphyses (3–4.5 μm vs. 5–6 μm) (Frolov et al. 2016).
The new species is different from *P. microstepposa* by darker thallus (greyish-brown to pale brown vs. ochre, grey or grey-white), rugose thallus (vs. flat thallus), thinner thallus (125–200 μm vs. 85–370 μm), smaller algal cells (5–15 μm diam. vs. 13.5–20.5 μm diam.), presence of pruina on disc (vs. absence of it), absence of oil droplets in hymenium (vs. presence of it), greyish epihymenium (vs. brownish epihymenium), wider ascospores (11–18 × 5.5–11 μm with the L/W ratio of 1.5–2.5 vs. 13.6–18.4 × 6–7.9 μm with the ratio of 1.9–2.9) (Frolov et al. 2016).

The new species is distinguished from *C. micromarina* by darker thallus (greyish-brown to pale brown vs. ochre to grey), rugose thallus (vs. flat thallus), absence of pruina on thallus (vs. presence of it), shorter hymenium (60–70 μm vs. 90–100 μm), shorter septum (1.5–3 μm vs. 2.6–3.4 μm) and the habitat preference to mountain rocks (vs. coastal rocks) (Frolov et al. 2016).

Additional specimens examined: South Korea, Gangwon Province, Okgye-myeon, Mt. Seokbyung (summit), 37°35.21’N, 128°53.87’E, 1,072 m alt., on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000889, with *Bagliettoa baldensis*, *Catillaria lenticularis*, *Fulgogasparrea decipioides* (Arup) S.Y. Kondr., M.H. Jeong.
Kärnefelt, Elix, A. Thell & Hur and Laundonia flavovirescens (Wulfen) S.Y. Kondr., Lőkös & Hur (BDNA-L-0001089); same locality, on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000909, with Bagliettoa baldensis, Rusavskia elegans (Link) S.Y. Kondr. & Kärnefelt and Verrucaria nigrescens Pers. (BDNA-L-0001109); same locality, on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000910, with Bagliettoa baldensis, Catillaria lenticularis and Laundonia flavovirescens (BDNA-L-0001110); same locality, on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000911, with Athallia cf. vitellinula, Bagliettoa baldensis, Lichenella sp. and Rusavskia elegans (BDNA-L-0001111); same locality, on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000913, with Athallia cf. vitellinula, Bagliettoa baldensis, Endocarpon sp., Laundonia flavovirescens, Lichenella sp. and Rusavskia elegans (BDNA-L-0001113); same locality, on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000916, with Caloplaca sp., Endocarpon sp., Lichenella sp. and Rusavskia elegans (BDNA-L-0001116).

Figure 5. Phylogenetic relationships amongst available species in the genera Huriella and Squamulea, based on a Maximum Likelihood analysis of the dataset of ITS sequences. The tree was rooted with the sequences of the genera Amundsenia, Erichansenia and Shackletonia. Maximum Likelihood bootstrap values ≥ 70% and posterior probabilities ≥ 95% are shown above internal branches. Branches with bootstrap values ≥ 90% are shown in bold. The new species Huriella aeruginosa is presented in bold and all species names are followed by the GenBank accession numbers. Reference Table 1 provides the species related to the specific GenBank accession numbers and voucher information.
**Huriella aeruginosa** B.G. Lee & J.-S. Hur, sp. nov.
MycoBank No: 839185
Fig. 7

**Diagnosis.** *Huriella aeruginosa* differs from *‘Squamulea’ chelonia* by dark greenish-grey to grey thallus without pruina (vs. yellow orange to deep orange thallus with white pruina), gold to yellow-brown epiphyemenium (vs. orange epiphyemenium), larger ascospores (7.5–12 × 4.5–7.5 μm vs. 8–10.4 × 4.7–6.0 μm) and the chemistry (thallus K–, KC– and no substance vs. thallus K+ purple, KC± purplish and the presence of parietin, teloschistin, fallacinal, parietinic acid and emodin).

**Type.** South Korea, Gangwon Province, Gangneung, Okgye-myeon, Mt. Seokbyung (summit), 37°35.21’N, 128°53.87’E, 1,072 m alt., on calcareous rock, 17 June 2020, B.G.Lee & H.J.Lee 2020-000872, with *Bagliettoa baldensis*, *Catillaria lenticularis*, *Endocarpon subramulosum* Y. Joshi & Hur, *Laundonia flavovirescens*, *Rusavskia elegans* and *Verrucaria nigrescens* (holotype: BDNA-L-0001072!; GenBank MW832829 for ITS).
Figure 7. *Huriella aeruginosa* (BDNA-L-0001072, holotype) in morphology A–C habitus and apothecia. Thallus dark greenish-grey to grey with no pruina. Thalline margin of apothecia concolorous to disc D apothecia adnate or rarely sessile. Amphithecium well-developed, but paratheciun inconspicuous. E thallus with dark green pigment layer under cortex F–G clavate asci containing 8-spores H ascospores generally ellipsoid, but occasionally globose, developing polarilocular in both types. Two blue coloured spores in lactophenol cotton blue. Scale bars: 1 mm (A–C); 100 μm (D);10 μm (E–H).

Thallus saxicolous (calcicolous), crustose, mainly areolate or slightly rimose, placodioid around edge, but without distinct lobes, thin, dark greenish-grey to grey, occasionally pale yellowish-grey when young, margin indeterminate or determinate when placodioid areoles are arranged around edge, vegetative propagules absent, areoles 0.3–0.7 mm diam., 150–200 μm thick; cortex hyaline with dark green pigment
layer, 15–25 μm thick, cortical cells granular, coarsely anticlinally arranged, 5–10 μm diam., with epinecral layer, up to 5 μm thick; medulla 80–100 μm thick, below algal layer, with large crystals (materials of substrate possibly) and brown cells (dead algal cells possibly); photobiont coccoid, cells globose to oval, 5–25 μm. Small crystals in cortex, medulla and between algal cells, dissolving in K. Prothallus absent.

Apothecia abundant, scattered and not concentrated in centre, rounded, often contiguous when mature, emerging on the surface of thallus, immersed, adnate or rarely sessile, constricted at the base, 0.2–0.4 mm diam. Disc flat when young and flat or slightly convex when mature, not pruinose, orange from the beginning, 110–230 μm thick; margin persistent, even to disc or slightly prominent, generally entire or slightly crenulate, thalline margin concolorous to disc, proper margin inconspicuous. Amphithecial well-developed, with small crystals between algal cells, dissolving in K, 50–55 μm wide laterally, algal layers continuous to the base or solitarily remaining in amphitheciu, algal cells 5–25 μm diam., cortical layer hyaline with gold to yellow-brown pigment concolorous to epihymenium at periphery, 15–20 μm thick. Parathecia inconspicuous, hyaline but gold to yellow-brown at periphery, ca. 10 μm wide laterally and ca. 20 μm wide at periphery. Epihymenium gold to yellow-brown, granular, pigment K+ wine red and dissolved, 10–20 μm high. Hymenium hyaline, 45–55 μm high. Hypothecium hyaline, 35–45 μm high. Oil droplets present, small, along paraphyses and more in the base of hymenium and hypothecium. Paraphyses septate, anastomosing, 2–3 μm wide, simple or branched at tips, tips swollen or slightly swollen, not pigmented, 3.5–5.5 μm wide. Asci clavate, 8-spored, 35–48 × 14–17 μm (n = 5). Ascospores generally ellipsoid, occasionally globose, 1-septate, polarilocular or narrow septum remaining, hyaline permanently, 7.5–12 × 4.5–7.5 μm (mean = 9.9 × 5.7 μm; SD = 0.9(L), 0.6(W); L/W ratio 1.2–2.3, ratio mean 1.8, ratio SD = 0.2; n = 104), globose spores 7.5–9 × 7.0–9.2 μm (mean = 8.0 × 7.7 μm; SD = 0.8(L), 0.9(W); L/W ratio 1.0–1.1, ratio mean = 1.0, ratio SD = 0.1; n = 11). Pycnidia not detected.

Chemistry. Thallus K–, KC–, C–, Pd–. Apothecia K+ wine red. Epihymenium K+ wine red. Epitymexium and hymenium I+ blue. UV–. No lichen substance was detected by TLC.

Distribution and ecology. The species occurs on the calcareous rock. The species is currently known from the type collection.

Etymology. The species epithet indicates the lichen’s thallus colour, dark green, which is the key characteristic distinguished from all the species in the genus Huriella.

Notes. The morphological classification of the new species is not clear between Huriella and Squamulea because the new species has some characteristics for the former genus and others for the latter, i.e. the new species represents mainly areolate thallus without lobed margin and smaller apothecia for the former, whilst showing some squamulose thallus and wider ascospores for the latter (Table 2). The molecular results concluded the new species classification into the former genus, Huriella.

The new species is unique with the key characteristics of green pigmented thallus (with a distinct green layer in a section) and the substrate preference to calcareous rocks amongst all Huriella species.
Table 2. Comparison of the new species with two type species in *Huriella* and *Squamulea*.

| Species        | *Huriella aeruginosa* | *Huriella loekoesiana* | *Squamulea subsoluta* |
|----------------|-----------------------|------------------------|-----------------------|
| Thallus        | mainly areolate, rimose or placoid around edge, but without lobes | areolate (not squamulose) | squamulose, areolate or subsquamulose, margin slightly lobed |
| Apothecia (mm in diam.) | 0.2–0.4 | 0.2–0.4(–0.5) | 0.1–0.6 |
| Ascospores (μm) | 7.5–12 × 4.5–7.5 | (8.5–)9–11(–12) × (4.5)5–6 | 9.5–12.5 × 5.5–7 |
| Molecular phylogeny | Huriella | Huriella | Squamulea |
| Reference | – | Kondratyk et al. 2017b | Nash III et al. 2007; Arup et al. 2013 |

The new species is similar to ‘*Squamulea* chelonia, *Squamulea galactophylla*, ‘*Squamulea humboldtiana*, *S. parviloba* and *S. subsoluta* in the substrate preference to calcareous rocks. However, the new species is different from ‘*Squamulea chelonia* by dark greenish-grey to grey thallus without pruina (vs. yellow orange to deep orange thallus with white pruina), gold to yellow-brown ephymenium (vs. orange ephymenium), larger ascospores (7.5–12 × 4.5–7.5 μm vs. 8–10.4 × 4.7–6.0 μm) and the chemistry (thallus K–, KC– and no substance vs. thallus K+ purple, KC± purplish and the presence of parietin, teloschistin, fallacinal, parietinic acid and emodin) (Bungartz et al. 2020).

The new species differs from *S. galactophylla* by thallus colour (dark greenish-grey to grey vs. dirty white to yellowish-brown), flat to convex disc (vs. flat disc only), yellowish-orange apothecia (vs. cinnamon-brown apothecia), smaller ascospores (7.5–12 × 4.5–7.5 μm vs. 10–15 × 5–7 μm) (Fink 1935; Arup 2013).

The new species is distinguished from ‘*Squamulea humboldtiana* by dark greenish-grey to grey thallus without pruina (vs. yellow-orange to deep orange thallus with pruina), absence of prothallus (vs. presence of prothallus), larger ascospores (7.5–12 × 4.5–7.5 μm vs. 8.1–9.9 × 4.8–5.9 μm) and the chemistry (thallus K–, KC– and no substance vs. thallus K+ purple, KC± purplish and the presence of parietin, teloschistin, fallacinal, parietinic acid and emodin) (Bungartz et al. 2020).

The new species differs from *S. parviloba* by dark greenish-grey to grey thallus (vs. yellow-orange to orange thallus), absence of lobes (vs. short narrow elongated lobes around edge), convex and yellow-orange disc (vs. flat and deep orange disc), smaller ascospores (7.5–12 × 4.5–7.5 μm vs. 11–14 × 5.5–7 μm) and the chemistry (thallus K– vs. thallus K+ red) (Wetmore 2003; Nash III et al. 2007).

The new species is different from *S. subsoluta* by dark greenish-grey to grey thallus (vs. yellow-orange, orange to reddish-orange thallus), absence of prothallus (vs. black prothallus), flat to convex, yellow-orange apothecia (vs. flat to concave, deep orange apothecia) and the chemistry (thallus K– and no substance vs. thallus K+ red, the presence of parietin, fallacinal, emodin and teloschistin) (Wetmore 2003; Nash III et al. 2007).

The most distinctive characteristic of the new species is the thallus colour, i.e. dark greenish-grey to grey, which is different from all comparable calcicolous species in the genus *Squamulea*. 
Key to the species of *Huriella* and *Squamulea* (20 taxa)

Although some species of *Huriella* have distinct characteristics, different from *Squamulea*, such as mainly areolate and non-squamulose thallus without lobes at margin, smaller apothecia and narrower ascospores (Kondratyuk et al. 2017b), those morphological taxonomic keys do not clearly separate the two genera concerning all known species in the genera. The morphological characteristics are assumingly based on the comparison between type species of the comparable genera, but several species do not correspond to the characteristics (e.g. *Huriella aeruginosa*, *H. flakusii* Wilk and *H. salyangiana* S.Y. Kondr. & Hur with squamulose thalli), although those species are classified in the genus *Huriella* in molecular phylogeny. Such a discrepancy between morphology and molecular phylogeny occur in *Squamulea squamosa* (B. de Lesd.) Arup, Søchting & Frödén and *S. subsoluta* as well. Both species are considered conspecific in morphology. Both species are very similar in morphology and ecology occurring together on the same rock. Whereas the only difference between them is that the former has a thalline margin and it is lacking in the latter (Nash III et al. 2007), the latter representing a permanent thalline margin from the Galapagos Islands as well (Bungartz et al. 2020). However, the two species are separated and located distant from each other in molecular results of this study (Fig. 5). Nevertheless, those are still considered conspecific in the key below as a taxonomic key is based mainly on ecology, morphology and chemistry. The genera *Huriella* and *Squamulea* should be more studied in the future and here a preliminary key is updated from previous taxonomic keys of Wetmore (2003) and Bungartz et al. (2020).

1 Not directly on rock, but on lichen or bone ........................................... 2
   – On rock ......................................................................................... 4
2 On lichen (*Aspicilia*) living on rock ................................................. *Squamulea nesodes*
   – On bone .......................................................................................... 3
3 Thallus generally areolate, without blastidia, not pruinose ..............
   ..........................................................................................................
   ‘*Squamulea* osseophila’
   – Thallus generally (sub)squamulose, blastidia abundant, not pruinose or faintly orange pruinose on thallus ........................................... ‘*Squamulea* phyllidizans’
4 On calcareous rocks ............................................................................. 5
   – On siliceous rocks ............................................................................ 10
5 Thallus pruinose .................................................................................. 6
   – Thallus not pruinose ........................................................................... 7
6 Thallus angular, areolate to subsquamulose, prothallus absent ........
   ..........................................................................................................
   ‘*Squamulea* chelonia’
   – Thallus areolate or bullate, prothallus black when present ..........
   ..........................................................................................................
   ‘*Squamulea* humboldtiana’
7 Thallus whitish, greyish or greenish ................................................... 8
   – Thallus yellow-orange to orange ...................................................... 9
8 Thallus dirty whitish, disc cinnamon-brown ....................................... *Squamulea galactophylla*
   – Thallus dark greenish-grey to grey, disc orange ......................... *Huriella aeruginosa*
9  Areole margins with small lobules..........................*Squamulea parviloba*
   – Areole margins without lobules..........................*Squamulea squamosa (S. subsoluta)*
 10  With blastidia or soredia..........................................................11
   – Without blastidia or soredia..........................................................13
 11  Thallus brownish-orange, apothecia rare, disc reddish to reddish-brown, ascospores 11–16 × 6–8 μm, isthmus 1–3 μm ........................................*Squamulea kiamae*
   – Thallus yellowish-orange to deep orange, apothecia common, disc concolorous to thallus or slightly deeper, ascospores 8.4–13.3 × 5–7.1 μm, isthmus 2.5–4.6 μm.................................12
 12  Blastidia abundant, sometimes faintly orange pruinose on thallus, but not pruinose on disc..........................................................‘*Squamulea phyllidizans*
   – Soredia rarely present, rarely white pruinose on disc, but not pruinose on thallus..........................................................*Squamulea squamosa (S. subsoluta)*
 13  Thallus areolate to (sub)squamulose..........................................................14
   – Thallus areolate or bullate, but not squamulose...............................21
 14  Prothallus distinctly blackened..............................................‘*Squamulea* oceanica*
   – Prothallus absent........................................................................15
   – Disc brownish to reddish or blackish...........................................16
   – Disc orangish................................................................................19
 15  Thallus orange, disc reddish, ascospores 11–14.2 × 5.9–7.5 μm..........................*Huriella flakusii*
   – Thallus brownish, disc pale brown, brownish-orange to blackish-brown ....17
 16  Disc 0.4–0.9 mm diam., hypothecium 50–100 μm high, ascospores 9–13 × 5–6 μm............................................*Squamulea coreana*
   – Disc 0.2–0.4 mm diam., hypothecium 100–150 μm high, ascospores 10–10.5 × 4.5–6 μm..........................................................*Squamulea uttarkashiana*
 17  Areole margins with small lobules............................................‘*Squamulea parviloba*
   – Areole margins without lobules..........................................................20
 18  Ascospores 8–10.4 × 4.7–6 μm, isthmus 2.1–3.3, not pruinose on disc..............‘*Squamulea* chelonia
   – Ascospores 8.4–13.3 × 5.2–7 μm, isthmus 2.5–4 μm, rarely pruinose on disc ............................................*Squamulea squamosa (S. subsoluta)*
 19  Thallus yellow-orange to deep orange, prothallus black when present, ascospores 8.1–9.9 × 4.8–5.9 μm, isthmus 2.7–3.2 μm...........‘*Squamulea* humboldtiana
   – Thallus yellow-brownish or yellow-greenish, prothallus absent, ascospores 9–15 × 5–8 μm, isthmus 2–5 μm ..................................................22
 20  Apothecia 0.2–0.3 mm diam., disc dull brown, dull yellow to bright yellow...
   – Apothecia 0.3–1 mm diam., disc orange, brownish-yellow to reddish-orange

21  Thallus yellow-orange to deep orange, prothallus black when present, ascospores 8.1–9.9 × 4.8–5.9 μm, isthmus 2.7–3.2 μm...........‘*Squamulea* humboldtiana
   – Thallus yellow-brownish or yellow-greenish, prothallus absent, ascospores 9–15 × 5–8 μm, isthmus 2–5 μm ..................................................22
 22  Apothecia 0.2–0.3 mm diam., disc dull brown, dull yellow to bright yellow...
   – Apothecia 0.3–1 mm diam., disc orange, brownish-yellow to reddish-orange

23  Apothecia 0.2–0.3 mm diam., disc dull brown, dull yellow to bright yellow...

24

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Korean calcicolous caloplacoid lichens

23 Disc dull yellow to bright yellow, hymenium 50–60 μm high, hypothecium 20–30 μm high, ascospores 9–11 × 5–6 μm, isthmus 4–5 μm ..................
............... Huriella loekoesiana
– Disc dull brown, hymenium 80–100 μm high, hypothecium 80–110 μm high, ascospores 13–14.5 × 7–8 μm, isthmus 3–4 μm... Huriella upretiana

24 On mountain, thallus yellow-brown, disc orange, isthmus 3–4 μm..............
............... Squumulea micromera
– On coast, thallus dull green-yellow to yellow-brown, disc orange to red-orange, isthmus 2–3 μm......................... Huriella pohangensis

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