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Diversity and distribution of the lichen genus *Umbilicaria* in the Argentine Islands–Kyiv Peninsula region, the maritime Antarctic

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This paper documents the occurrence of the genus *Umbilicaria* in the Argentine Islands–Kyiv Peninsula region of the Graham Coast in the maritime Antarctic. The presence of seven *Umbilicaria* species (*U. africana*, *U. antarctica*, *U. aprina*, *U. decussata*, *U. kappenii*, *U. nylanderiana* and *U. umbilicarioides*) in the ice-free areas of the Argentine Islands–Kyiv Peninsula region were confirmed. The species of *U. africana* and *U. aprina* are documented from the studied region for the first time. This study moves the southern distribution limit of *U. africana* about 300 km to the south: to the Argentine Islands–Kyiv Peninsula region. The distribution maps of *Umbilicaria* species for the studied region and maritime Antarctica are prepared.

Keywords Macrolichens, New records, ITS, *Umbilicaria africana*

In the world, *Umbilicaria* species are widely distributed in alpine and bipolar habitats. This genus is easily distinguished by foliose thalli growing on rocks, attached to the substratum at a single point by a short strand called an umbilicus. The specimens of this genus can reach the thalli sizes from one to 30 cm in diameter or more, e.g. *U. antarctica*[1,2]. The *Umbilicaria* lichens grow on stable, rugged and weather-resistant acidic rocky substrates. In the Antarctic, the *Umbilicaria* genus is widespread and often locally abundant. It occurs less frequently on south-facing rocks and is absent on cliffs and boulders exposed to wind and salt spray[1–4].

Although the *Umbilicaria* genus is distinct and well distinguished from other genera of lichens, the species among themselves are difficult to determine, especially in the field. The specimens of this genus are probably still overlooked during hard, polar fieldwork and limited access to the spots where *Umbilicaria* are abundant. This explains why the species of *Umbilicaria* are still discovered in Antarctica as new to science[5] or as new to the region[4,6]. Øvstedal and Lewis Smith[2] reported 10 species of *Umbilicaria* in the Antarctic region. In contrast, on the Argentine Islands–Kyiv Peninsula region, five species have been published from this region by Smith and Corner[7] and Gremmen et al.[8], and BAS Database[9], including *U. antarctica*, *U. decussata, U. kappenii, U. nylanderiana* and *U. umbilicarioides*. Whereas on the South Shetland Islands neighbouring the Antarctic Peninsula, as many as nine species of *Umbilicaria* were reported[1,4]. In the Argentine Islands–Kyiv Peninsula region, Smith and Corner[7] identified *Umbilicaria* species in sub-formation called fruticose lichen and moss cushion in three sociations, such as *Andreaea-Dicranoweisia grimmiacea-Usnea-Umbilicaria, Andreaea-Grimmia-Usnea-Umbilicaria* and *Usnea-Umbilicaria decussata-Alectoria*. Based on the environmental analysis, Gremmen et al.[8] identified communities with *Umbilicaria* as the *Usnea* complex. These communities are developed on the rocks, debris and ledges formed by erosion, conditioned by the limited inflow of organic matter from birds and relatively low concentration of chlorides[8]. Water from melting snow flows into them. They are also exposed to sunlight and UV rays, and in winter they freeze without a permanent snow cover.

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Lichens (symbiotic organisms, lichenized fungi) are generally very sensitive to environmental changes and respond quickly. They are sensitive because of their internal structure and physiological features. They are long-living, ectohydric organisms with a limited ability to regulate gas and water exchange. Both nutrients and toxic elements dissolved in the atmosphere are absorbed through the whole surface of the thalli[10]. In the 1990s rapid warming was observed in the maritime Antarctic[11]. It resulted in changes in the original communities of vascular plants and cryptogams[12–14]. Some changes related to this phenomenon have been shown in the Oasis Lions Ramp on King George Island, i.e. it was observed, during the long-term experiment on the dynamics of the lichen biota within the Antarctic Specially Protected Area No. 151[15]. According to other studies during ten years of observation, the cover of the dominant lichen *Usnea antarctica* Du Rietz declined by 71% in the study plots[16]. It seems very important, to study the actual composition of the lichen flora and communities in the maritime Antarctic to determine the direction of upcoming changes.

In this paper, the authors present data collected during their current fieldwork and historical data from previous expeditions[7–9]. Authors discuss the occurrence, status and ecological features of the *Umbilicaria* lichens in the area in the context of the overall distribution in the study region.

Material and methods

Study area

The Argentine Islands are located on a coastal shelf in the western part of the Antarctic Peninsula, 2–6 km from the coastal line of the Kyiv Peninsula (Fig. 1). It is a group of low ice-capped islands laying 6–12 km west of the Graham Coast and separated from the mainland by the Penola Strait water. They consist of more than 40 islands of different sizes. They form some groups separated by inter-island waters with depths of less than 50 m. The largest of this group are Skua Island (0.6 km^2) and Galindez Island (0.4 km^2), and the highest point is placed on Uruguay Island (65 m a.s.l.). The Ukrainian Academic Vernadsky Antarctic Station is located on Galindez Island, Marina Point (65° 14′ 45.2″ S, 64° 15′ 27.7″ W)[17,18].

The Argentine Islands–Kyiv Peninsula region is composed mainly of volcanic igneous and intrusive rocks. Islands' coasts are mostly steep and rocky, almost without abrasive terraces or beaches. The western shore of the Antarctic Peninsula is a part of the maritime Antarctic and has a mild and humid climate. The mean annual air temperature varies from − 2.4 to − 5.4 °C. The mean air temperatures of the summer months are above zero, and the highest exceed + 10 °C[18]. The mean temperatures of the coldest months (June–August) seldom fall beyond − 15 °C[7]. The absolute minimum of − 43.3 °C was detected on the Argentine Islands in August 1958, and the maximum of + 11.7 °C—in February 1960[18]. The Argentine Islands are somewhat north of the Southern Polar Circle, so the classic polar night does not occur there. During the Antarctic winter solstice (June 22), the Sun rises above the horizon by almost 3 degrees[19]. The sum of the light time during the day is maximal from the second half of November until the end of January, i.e. during the polar day[20]. The average air humidity in the region is 86%, and the average annual precipitation is 433 mm with a coefficient of variation of 0.32. The predominant type of precipitation is snow. In some years, its thickness can reach almost 3 m, however, in rocky areas, these values are rather significant[21].

Materials

The field studies were carried out in the Argentine Islands–Kyiv Peninsula region during the Ukrainian Antarctic Expeditions in the austral summer seasons of 2018/19, 2019/20, 2020/21 and 2021/22. Samples were packed into sampling bags with notes describing the sites: altitude, substrate, type of vegetation and coordinates. The geographical names of the sampling sites are given following Yevchun et al.[22]. In addition, some unpublished materials of *Umbilicaria* from the Danco Coast and Victoria Land, and specimens from King George Island curetted at the KRAM L herbarium were included to achieve a more complete view of species distribution and/or for molecular analysis.

The voucher specimens were deposited in the Herbarium of the W. Szafer Institute of Botany of the Polish Academy of Sciences in Krakow (KRAM L), (Appendix 1S). The thallus material for nuclear ITS rDNA sequence analysis was obtained from 18 specimens of *Umbilicaria* (GenBank Accession Numbers PP580112, PP580129). The specimens for DNA analysis were only air-dried at room temperature. The details of the analysed specimens and GenBank accession numbers are presented in Table 1. The morphology was examined using a standard stereomicroscope Nikon SMZ 645 and a compound microscope Nikon Eclipse E200. Measurements were made in water or c. 5% KOH.

DNA extraction, PCR amplification

The total DNA was extracted from fresh and herbarium materials. The small, ground samples from herbarium specimens were prepared. Next, they were extracted in acetone for 1 h to remove secondary lichen products. The acetone was discarded and the samples were dried at room temperature to let the acetone evaporate. The total genomic DNA was extracted using DNeasy Plant Mini Kit (Qiagen) following the manufacturer's instructions. The PCR reaction was performed in 25 µl volume comprising 3 µl of DNA template, 2.5 µl of 10 × AmpliTaq 360 PCR Buffer, 2.5 µl 25 mM MgCl2, 0.5 µl dNTPs (10 mM each; Sigma Aldrich), 0.2 µl of AmpliTaq 360 DNA polymerase (Applied Biosystems), 0.2 µl of bovine serum albumin (BSA; New England Biolabs), 1 µl of forward and reverse primer (10 µM), and sterile distilled water was added to attain the final volume. The fungi primers for the nuclear ITS rDNA selected for the reaction were: nu–SSU–1752–5′ (ITS1F)[28] and nu–LSU–0041–3′ (ITS4)[29].

The reactions run with the following parameters for the nuclear ITS rDNA: initial denaturation at 95 °C for 5 min, then 5 cycles of denaturation at 95 °C for 30 s, annealing at 54 °C for 30 s, and extension at 72 °C for 1 min, followed by 33 cycles of denaturation at 95 °C for 30 s, annealing at 48 °C for 30 s, and extension at 72 °C for 1 min, with a final extension at 72 °C for 10 min and a 4 °C hold. PCR products were visualized by running

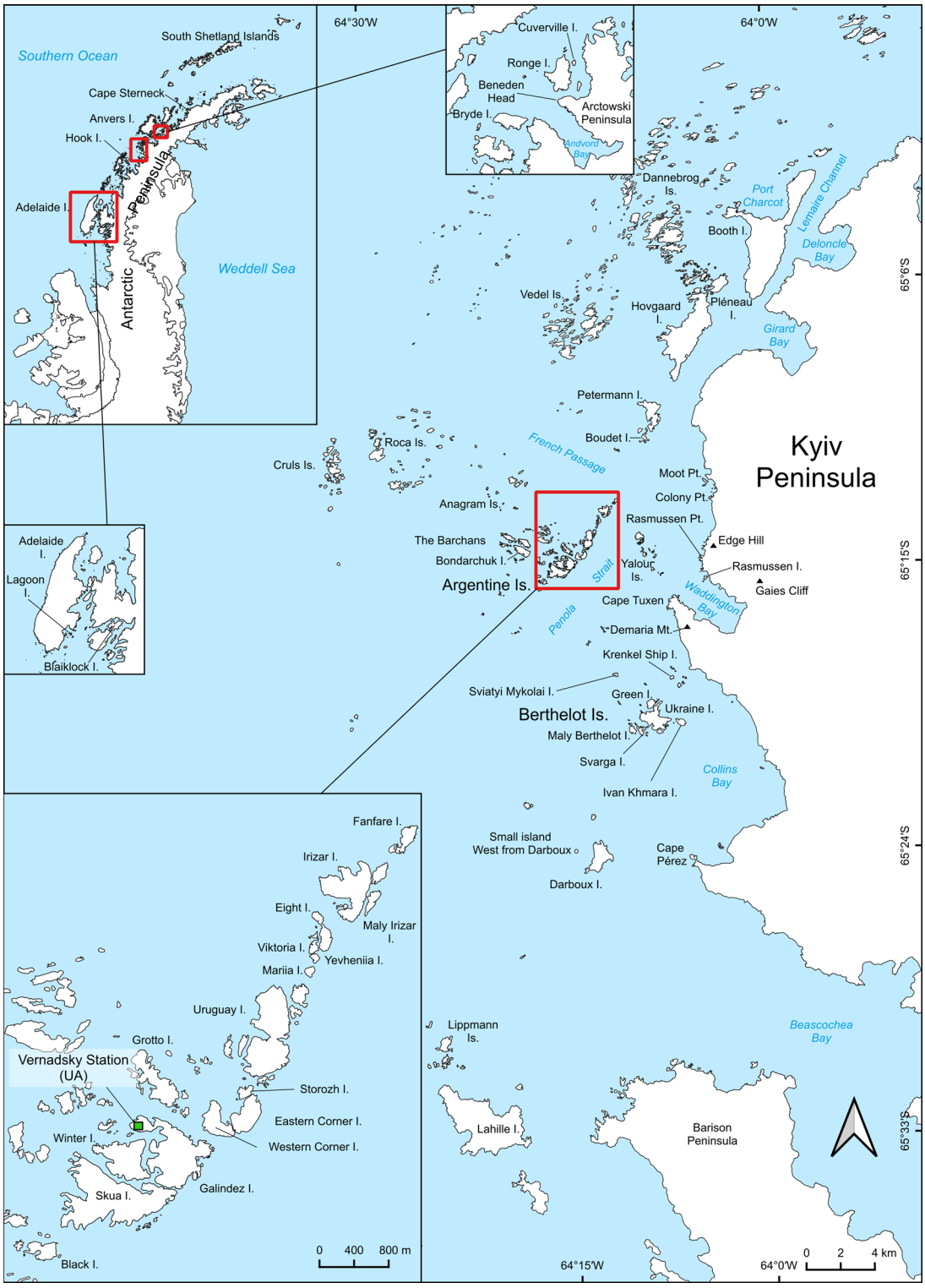

Figure 1. Map showing the location of the Argentine Islands–Kyiv Peninsula region and the Antarctic Peninsula. Names given on the maps represent the locations of the *Umbilicaria* sampling sites.

3 µl of the PCR product on 1% agarose gels. The PCR products were subsequently purified using the mixture of exonuclease (10 U/µl, 5000 U, EurX) and shrimp alkaline phosphatase (1 U/µl, 1000 U, Applied Biosystems). Purified PCR products were sequenced by Macrogen (Amsterdam, Netherlands) using the same amplification primers. The ITS1–5.8S–ITS2 rDNA sequences were generated bidirectionally and read by GATC Biotech AG (Germany). Consensus sequences were obtained manually with Geneious Prime 2022.1.1. (https://www.geneioues.com). The ITS1–5.8S–ITS2 rDNA sequences generated in this study have been deposited in the NCBI nucleotide sequence database (https://www.ncbi.nlm.nih.gov) under accession numbers (Table 1).

Species	Country/locality	Collector/herbarium	Gen bank acc. no. ITS	References
Umbilicaria africana	Chile, XII Region	S. Perez-Ortega, F. Fernandez-Mendoza 1774 (Herb. Perez-Ortega)	KY947844	Davydov et al.[23]
Umbilicaria africana	Peru	Hestmark 05081B (O)	HM161482	Hestmark et al.[24]
Umbilicaria africana	Antarctica, King George I	J. Smykla (KRAM-L 47134)	**PP580116**	this study
Umbilicaria africana	Bolivia	A. Flakus & P. Rodriguez (KRAM-L 71889)	**PP580113**	this study
Umbilicaria africana	Antarctica, Galindez I	I. Parnikoza (KRAM-L 72707)	**PP580112**	this study
Umbilicaria antarctica	Antarctica	NH	AF096213	Ivanova et al.[25]
Umbilicaria antarctica	Antarctica, Barton	M.P. Andreev L03951 (ALTB)	KY947849	Davydov et al.[23]
Umbilicaria antarctica	Antarctica, Eastern Corner I	I. Parnikoza (KRAM-L 72668b)	**PP580127**	this study
Umbilicaria antarctica	Antarctica, Ivan Khmara I	I. Parnikoza (KRAM-L 72745)	**PP580123**	this study
Umbilicaria aprina	Antarctica, Victoria Land	J. Smykla (KRAM-L 72940)	**PP580114**	this study
Umbilicaria aprina	Antarctica, Skua I	I. Parnikoza (KRAM-L 72709)	**PP580115**	this study
Umbilicaria aprina	Indian Himalayas	Herb. Saini,K.C	MZ919295	Saini et al., unpubl
Umbilicaria aprina	Antarctica, McMurdo Dry Valleys,	–	JX036039	Pérez-Ortega et al.[26]
Umbilicaria aprina	Antarctica, McMurdo Dry Valleys,	–	JX036075	Pérez-Ortega et al.[26]
Umbilicaria badia	Nepal	Sharma & al. s.n. (E00321836)	KY947738	Davydov et al.[23]
Umbilicaria crustulosa	Austria	W. Obermayer 7104 (H)	KY947761	Davydov et al.[23]
Umbilicaria decussata	Antarctica, Lagoon I	S. Ott, (hb. Ott 2007)	AY603122	Ott et al.[27]
Umbilicaria decussata	Svalbard		KP314429	Zhang unpubl
Umbilicaria decussata	Antarctica, Eastern Corner I	I. Parnikoza (KRAM-L 72736)	**PP580119**	this study
Umbilicaria decussata	Antarctica, Galindez I	I. Parnikoza (KRAM-L 72728)	**PP580120**	this study
Umbilicaria decussata	Ecuador	Hestmark 94074 (O)	HM161510	Hestmark et al.[24]
Umbilicaria decussata	–	NH	AF096214	Ivanova et al.[25]
Umbilicaria dendrophora	Finland	H. Väre L 1777 (H)	KY947772	Davydov et al.[23]
Umbilicaria deusta	Russia, Altai	E.A. Davydov 5353 (ALTB)	KY947753	Davydov et al.[23]
Umbilicaria grisea	Ukraine	O.B. Blum (ALTB)	KY947848	Davydov et al.[23]
Umbilicaria hyperborea	Russia, Karelia	A.A. Zavarzin s.n. (ALTB-L148)	KY947998	Davydov et al.[23]
Umbilicaria indica	China, Yunnan	A.A. Zavarzin s.n. (ALTB-L170)	KY948006	Davydov et al.[23]
Umbilicaria kappeni	Antarctica, Lagoon I	hb. Ott 2008	AY603132	Ott et al.[27]
Umbilicaria kappeni	Antarctica, Western Corner I	I. Parnikoza (KRAM-L 72744)	**PP580128**	this study
Umbilicaria kappeni	Antarctica, Uruguay I	I. Parnikoza (KRAM-L 72669)	**PP580126**	this study
Umbilicaria kisovana	Russia, Primorye region	I.S. Zhdanov s.n. (ALTB-L190)	KY947737	Davydov et al.[23]
Umbilicaria krasheninnikovii	Antarctica, Livingston I	F	AY603134	Ott et al.[27]
Umbilicaria krasheninnikovii	–	–	JQ739994	Zhang et al. unpubl
Umbilicaria krasheninnikovii	Russia, Kamchatka	H	KY947857	Davydov et al.[23]
Umbilicaria leiocarpa	France	D.M. Masson 2B.4194 (ALTB)	KY947846	Davydov et al.[23]
Umbilicaria mammulata	U.S.A., Minnesota	C.M. Wetmore 82463 (M-0083027)	KY947819	Davydov et al.[23]
Umbilicaria muehlenbergii	Russia, Altai	E.A. Davydov 5360 (ALTB)	KY948005	Davydov et al.[23]
Umbilicaria nylanderiana	Bolivia	Hestmark 05009B (O)	HM161488	Hestmark et al.[24]
Umbilicaria nylanderiana	Russia, Altai	E.A. Davydov 5295 (ALTB)	KY947855	Davydov et al.[23]
Umbilicaria nylanderiana	Antarctica, Galindez I	I. Parnikoza (KRAM-L 72704)	**PP580122**	this study
Umbilicaria nylanderiana	Antarctica, Winter I	I. Parnikoza (KRAM-L 72703)	**PP580121**	this study
Umbilicaria polyphylla	Finland	V. Haikonen 21060 (H)	KY947763	Davydov et al.[23]
Umbilicaria rigida	Norway	E.A. Davydov 5367 (ALTB)	KY947749	Davydov et al.[23]
Umbilicaria subglabra	France	Ph. Clerk 2215 (ALTB-L205)	KY947861	Davydov et al.[23]
Umbilicaria thamnodes	China, Yunnan	A.A. Zavarzin s.n. (ALTB-L173)	KY947769	Davydov et al.[23]
Umbilicaria thamnodes	China, Yunnan	A. Aptroot 55697 (ALTB-166)	KY947825	Davydov et al.[23]
Umbilicaria umbilicarioides	Antarctica, Lagoon I	S. Ott (hb. Ott 2011)	AY603121	Ott et al.[27]
Umbilicaria umbilicarioides	Chile, XII Region	S. Perez-Ortega and F. Fernandez-Mendoza 1773 (Herb. Perez-Ortega)	KY947842	Davydov et al.[23]
Umbilicaria umbilicarioides	Antarctica, Skua I	I. Parnikoza (KRAM-L 72758)	**PP580118**	This study
Umbilicaria umbilicarioides	Antarctica, Uruguay I	I. Parnikoza (KRAM-L 72700)	**PP580124**	This study
Umbilicaria umbilicarioides	Antarctica, Galindez I	I. Parnikoza (KRAM-L 72701)	**PP580125**	This study
Umbilicaria umbilicarioides	Antarctica, Western Corner I	I. Parnikoza (KRAM-L 72749)	**PP580117**	This study
Umbilicaria umbilicarioides	Antarctica, Winter I	I. Parnikoza (KRAM-L 72757)	**PP580129**	This study
Umbilicaria vellea	Russia, Laplandsky Reserve	I.N. Urbanavichene (ALTB-5163)	KY947801	Davydov et al.[23]
Continued				

Species	Country/locality	Collector/herbarium	Gen bank acc. no. ITS	References
Umbilicaria yunnana	China, Yunnan	A.A.Zavarzin s.n. (ALTB-L169)	KY947770	Davydov et al.[23]
Xylopsora friesii	Russia, Murmansk Region	G.P. Urbanavichus s.n. (INEP-48)	KY947740	Davydov et al.[23]

Table 1. Sequenced species and specimens used in phylogenetic analyses with location, collection detail, GenBank accession number and references. The GenBank accession numbers of new sequences are in bold.

Phylogenetic analyses

The newly obtained sequences were compared in GenBank using BLASTn search[30]. Highly similar sequences were chosen for phylogenetic analyses (Table 1). The sequences were aligned with the MAFFT v.7.490[31,32] plugin implemented in Geneious Prime 2022.1.1 (https://www.geneioues.com) and adjusted manually. The maximum-likelihood (ML) analysis was conducted in IQ-TREE version 1.6.12[33]. IQ-TREE with the -m TEST options was run so that ModelFinder[34] would find the best-fitting substitution model. In total, 5000 ultrafast bootstrap pseudoreplicates were performed to calculate support for the analysed tree[35,36]. The calculated tree was rooted with *Xylopsora friesii* (Ach.) Bendiksby and Timdal KY947740. The results were visualised using FigTree 1.4.4. On the diagram, the posterior probabilities and ML bootstrap values are placed on well-supported branches [SH-aLRT support (%) / ultrafast bootstrap support (%)].

Results and discussion

Species diversity of the genus *Umbilicaria*

In the surveyed area seven *Umbilicaria* species were determined in the materials originating from the ice-free areas. The list of recorded species comprises: *U. africana* (Jatta) Krog and Swinscow, *U. antarctica* Frey and I.M. Lamb, *U. aprina* Nyl., *U. decussata* (Vill.) Zahlbr., *U. kappenii* Sancho, Schroeter and Valladares, *U. nylanderiana* (Zahlbr.) H. Magn. and *U. umbilicarioides* (Stein) Krog and Swinscow. Information is given below concerning their morphological characteristics and results of phylogenetic analysis.

Morphological characteristics

The investigated species of *Umbilicaria,* based on their morphological features, can be divided into two distinct groups: one with rhizines on the lower surface of their thalli (i.e.: *U. africana, U. antarctica, U. aprina, U. kappenii,* and *U. umbilicarioides*) and the other without rhizines (i.e.: *U. decussata* and *U. nylanderiana*).

Umbilicaria decussata, one of the species without rhizines, is very distinct and relatively easily distinguished from other species of the genus, particularly due to the upper surface with white wrinkled structures organised in a reticular pattern. The upper side is generally dark grey to grey-brown and scabrous, with a white necral layer in the central part, and sharp ridges radiating from the centre, fading into a reticulate pattern of weak ridges towards the periphery. However, this is quite a variable species, the most remarkable extremes being specimens with a completely smooth upper surface, and specimens with a laciniate outline to the margin[2]. On the other hand, the lower surface is completely sooty black (except for the margin, which is grey to brown), covered with unicellular, rarely bicellular thalloconidia a characteristic feature of the species. *U. decussata* most frequently reproduces vegetatively by thalloconidia[35,36] and has rarely been recorded with fertile thalli in Antarctica[2,4]. Similarly, in our study, among all recorded sites fertile specimens were found only on Black Island (KRAM-L 72735).

Although *U. decussata* is easily distinguished from other species of the genus, it is sometimes confused with *U. krasheninnikovii,* which has a very similar upper side of its thallus. Meanwhile, *U. krasheninnikovii* differs clearly in the appearance of its lower surface which is pale brown, without black patches, and lacks thalloconidia. However, in the field, both species can be confused due to similarities in the appearance of the upper side of their thalli[1]. The lack of records of *U. krasheninnikovii* in the investigated area may be due to the species being overlooked during field surveys because the first field identification is based only on the upper surface.

Umbilicaria nylanderiana, similarly to *U. decussata* has no rhizines. It is also characterized by unicellular thalloconidia created in sooty black patches on the lower surface. However, it can be distinguished from *U. decussata* by the presence of brown vermiform ridges on the upper surface of the thallus. The thallus of *U. nylanderiana* is usually monophyllous, though in our study a few polypyllous thalli were also found, particularly in wind-exposed habitats. The Antarctic specimens grow only up to ca. 2 cm in diameter[2]. Thus, they are considerably smaller compared to specimens from other regions where this species usually reaches 3–5 cm in favourable conditions and up even to 15 cm across[37].

In the past *U. nylanderiana* was often mistakenly reported from Antarctica as *U. hyperborea* (Ach.) Hoffm.,[4]. In fact, in our study, juvenile specimens of *U. nylanderiana* (up to 0.5 cm in diameter), with a brown lower side of the thallus, without black patches and thalloconidia (similar as in the mature specimens of *U. hyperborea*) were often observed in the Wilhelm Archipelago area. The pale brown lower side of their thalli is typical for the juvenile specimens of *U. nylanderiana* that have not yet started producing black thalloconidia. While *U. nylanderiana* and *U. hyperborea* are generally easily distinguished by their morphology, in the case of the latter which has rather more delicate and fragile thallus, with brown, vermiform folded upper surface, apothecia that tend to be embedded among the folds in smaller specimens, these differences might be inconspicuous. It is likely, therefore, that records of *U. hyperborea* from Green Island[9] and other records of this species from Antarctica[38] or elsewhere in the Southern Hemisphere may relate to juvenile forms of *U. nylanderiana*, whereas the distribution of *U. hyperborea* seems to be restricted to boreal zone with less harsh climatic conditions[39].

Among the species characterised by the presence of the rhizines, only *U. umbilicarioides* have dark brown to black rhizines richly branched at the top part (tree-like). Similarly, *U. cristata* also possesses multi-divided rhizines from one point and barred multicellular thalloconidia, but rhizines of that species are pale and grouped on the lower surface. *Umbilicaria umbilicarioides* has multi-cellular thalloconidia produced on the apices of richly branched, black rhizines placed mainly in marginal parts of the lower surface. The other rhizinate *Umbilicaria* species are recognized by only simple, dichotomous or rarely irregularly multi-branched rhizines.

Specimens of *U. umbilicarioides* investigated during current work are very variable. They had mono- to polyphyllous thalli, from one to 3–4 cm in diameter, only exceptionally larger up to 6 cm. These large specimens were characterized by ashy grey to blackish upper surface, often pale grey pruinose with well visible black rhizines in the marginal part. However, the upper side of some of the investigated specimens was pale brown. Probably these thalli were not light exposed. The lower sides of the thalli were smooth and pale beige-brown, sometimes nearly pinkish with only a dark and scabrous part around the umbilicus to scabrous and black throughout. The rhizines were abundant, mostly black terete, richly branched, shrubby to coralloid, and thallyles frequent, especially in the materials from Skua Island. These rhizines' tops are covered with black multi-cellular thalloconidia, appearing as a black rim around the thallus when it is seen from above. The Antarctic specimens are generally sterile[2]. However, single specimens with immature apothecia were reported from Galindez Island[40] and King George Island[1].

Multicellular thalloconidia are also present in *U. africana*, but they are produced on the lower surface of the thallus in sooty black patches. The specimens of *U. africana* found in Antarctica are generally small and reach only up to ca. 4 cm in diameter, the specimens from other regions are bigger, for instance in South America they reach up to 6 cm in diameter. The biggest specimens, up to 14 cm in diameter, were found in Africa.

The Antarctic specimens of *U. africana* can be confused with the juvenile specimens of *U. antarctica* and *U. aprina*. However, *U. africana* can easily be distinguished by pale to pale grey, simple to dichotomously branched or occasionally richly branched rhizines, circular in section, grey to brownish grey on the upper surface with dark marginal rhizines giving a ciliate appearance and by multi-cellular thalloconidia (4–10-celled, 20–40 µm diam.) bared in sooty black patches on the lower surface not on rhizines[1]. *Umbilicaria antarctica* and *U. aprina* also bared thalloconidia in black patches on the lower surface and have rhizines on the lower surface but differ in the presence of unicellular, rarely 1-septate thalloconidia.

Moreover, in the field, *U. antarctica* is often easily distinguished by its conspicuous size, with individual thalli reaching even 30 cm or more across[1,2]. However, in our study, such large specimens were recorded only on Darboux Island on the high steep rock walls. *Umbilicaria antarctica* is very variable and only the largest specimens can easily be distinguished during fieldwork. The other species of *Umbilicaria* generally grow only up to 7 cm in diameter, and only the thalli of *U. kappenii* and less frequently of *U. aprina* can reach up to 15 cm in diameter. Small specimens of *U. antarctica* can easily be confused with these two species. The most important characteristics distinguishing *U. kappenii* are the presence of dark brown soredia on the upper side and the lack of thalloconidia on the lower side of the thallus. In contrast, *U. antarctica* lacks soredia but its lower side is covered with unicellular thalloconidia which makes the lower side of the thallus distinctly black. While *U. aprina* also possesses black unicellular thalloconidia, it can be distinguished from *U. antarctica* by the lack of strap-like rhizines and its upper side of the thallus is more or less reticulate scabrous over the umbilicus.

Umbilicaria kappenii has dark brown soredia on the upper side of the margin and lacks thalloconidia on the lower side of the thallus whereas *U. antarctica* has unicellular thalloconidia and lacks soredia. The Lower side of *U. kappenii* is light brown, purple-brown or ash-grey, sometimes only brown-black around the umbilicus whereas *U. antarctica* is black on the lower side.

Phylogenetic analysis

The phylogenetic analyses involved 57 nucleotide sequences. The new 19 fungal ITS nrDNA sequences were aligned with 38 sequences available in the Genbank to produce a matrix (Table 1). The 19 newly obtained sequences were between 565 and 859 bp long. There was a total of 598 positions in the final dataset. The Bayesian inference and maximum-likelihood analyses yielded consistent tree topologies. The results are shown (Fig. 2) on a consensus tree obtained in ML analyses. The posterior probabilities and the ML bootstrap values are placed above the well-supported branches (SH-aLRT support 82%, ultrafast bootstrap support 96%).

The highest support (100% ultrafast bootstrap support) was observed in two clades, one with the sequences of *U. nylanderiana* and the other with *U. umbilicarioides*. Two newly received sequences of *U. nylanderiana* from Galindez and Winter Islands were clade together with the sequences of *U. nylanderiana* from the GenBank from Russia and Bolivia. These sequences are separated very well on the cladogram, with 97.8% SH-aLRT support and 100% ultrafast bootstrap support. The clade with *U. umbilicarioides* has also high support (97.3% and 100%, respectively) and encloses sequences obtained from Antarctic and Chilean material from the GenBank. The population of *U. umbilicarioides* from Antarctica seems to be genetically homogenous. The newly received sequences are very similar although the material was collected from different scattered locations (such as Galindez, Skua, Uruguay, Winter and Western Corner Islands). It is important to indicate that some untypical small brownish thalli, initially classified as belonging to *U. cristata* based on their morphological characteristics, during the genetic analyses of ITS nuDNA region (sequences PP580124 and PP580125, Fig. 2) claded together with *U. umbilicarioides*; thus, these specimens most likely represent juvenile forms of *U. umbilicarioides*.

Umbilicaria africana and *U. aprina* were also separated into well-supported clades. The newly received sequences of *U. aprina* from Antarctica clade together with sequences from the GenBank from the Himalayas and Antarctica. The samples of *U. aprina* were separated very well on the cladogram, with 95.6% SH-aLRT support and 96% ultrafast bootstrap support. However, the population of *U. africana* seems to be diverse having two well-supported branches. One with the sequences from Galindez Island (PP580112), Chile (GenBank KY 947844) and King George Island (PP580116) (with support 90/97) and the other with the sequences from

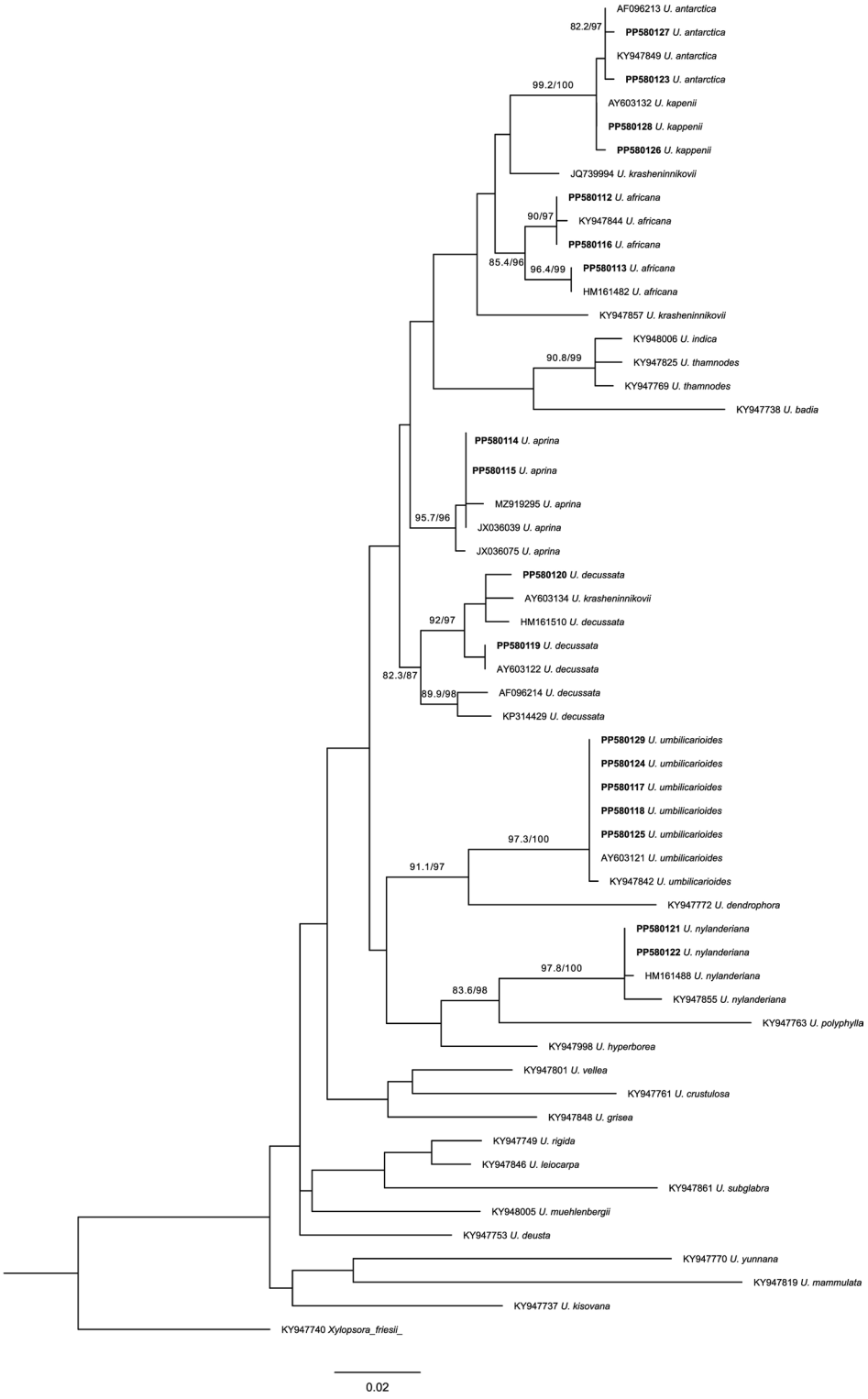

Figure 2. Maximum likelihood phylogenetic tree of the ITS1-5 8S-ITS2 rDNA sequences of *Umbilicaria* species. Newly generated sequences are given in bold. The tree is rooted with sequences of *Xylospora friesii*. The posterior probabilities and ML bootstrap values are placed on well-supported branches [SH-aLRT support (%) / ultrafast bootstrap support (%)].

Bolivia (PP580112) and Peru (GenBank HM161482) (85.4/96) (Fig. 2). It is important to note that the specimen from King George Island (PP580116) was previously reported by Krzewicka and Smykla[1] as *U. cristata* as it had all morphological characteristics typical of that species. However, our current genetic analyses demonstrated that this material represented juvenile specimens of *U. africana*. It seems likely that all previous reports of *U.*

cristata from Antarctica may refer to juvenile specimens of *U. africana* or *U. umbilicarioides*—the species also distinguished by the ciliate appearance. Unfortunately, there are no sequences of *U. cristata* available in GenBank. Therefore, re-examination and molecular analyses of other specimens determined previously as *U. cristata* are necessary to verify their taxonomic position.

The two newly received sequences of *U. decussata* from Antarctica clade with sequences of *U. decussata* from the GenBank. However, it is worth indicating an unusual position of the sequence of *U. krasheninnikovii* within this clade (Fig. 2). The sequences received from the specimens of *U. krasheninnikovii* seem to be generally very problematic in molecular analyses. For instance, three different ITS sequences of *U. krasheninnikovii* from the GenBank (i.e.: AY603134, JQ739994, KY947857) surprisingly clade in three separate clades (Fig. 2). However, the sequence AY603134 clade with *U. decussata* likely belongs to the latter species. During this study, we also prepared the ITS sequences (not included in the final analysis) from *U. krasheninnikovii* specimens collected previously on King George Island (KRAM-L 47133[1]) possessing all typical key features of the species (confirmed by *Umbilicaria* specialist—B. Krzewicka). Surprisingly, ITS sequence of this specimen of *U. krasheninnikovii* clades together with *U. antarctica*. Maybe it is a result of the morphological structure of *U. krasheninnikovii* thallus which probably is easily settled by other diasporas of *Umbilicaria* that are sequenced instead of the main material.

The clade with sequences of *U. antarctica* and *U. kappenii* is well-supported (99.2/100). The support for individual clades is considerably lower, for instance for *U. antarctica* up to 82.2% SH-aLRT support and 97% ultrafast bootstrap support. While both these species can easily be distinguished by their morphological and anatomical features, they remain genetically closely related, forming one clad. For this reason, based on molecular data alone, Otto et al.[41] treated both taxa as one species *U. antarctica.* According to recent trends, modern taxonomy should be based on genetics and classical taxonomy[41,42]. The differences between *U. antarctica* and *U. kappenii* have also been discussed in detail in previous literature[1,2,5]. Therefore, contrary to the suggestion of Otto et al.[27] in this study we consider both taxa as valid separate species.

Antarctic species of Umbilicaria not recorded in the study area

Of the 10 *Umbilicaria* species recorded in Antarctica[1,2] only four were not found within the study area, including *U. cristata* Dodge and Baker, *U. krascheninnikovii* (Savicz) Zahlbr., *U. saviczii* Llano and *U.* aff. *thamnodes* Hue.

Umbilicaria cristata is an Antarctic endemic reported from South Georgia I. and South Orkneys Is., the Antarctic Peninsula (rare) and the continental Antarctic (scarce)[2]. In our study, all specimens with ciliate appearance that resembled *U. cristata* turned out to be small, juvenile specimens of *U. africana* or *U. umbilicarioides* which are also characterized by ciliate appearance.

Umbilicaria krascheninnikovii was reported from the South Orkney Islands and the South Shetland Islands (Livingstone and King George Islands), and south of the Antarctic Peninsula to ca. 70°S[2,43,44]. In the North Hemisphere, it was previously reported from Svalbard at 78° N[45]. Currently, this species is known also from many other localities in the N Hemisphere, including the Arctic and the Himalayas[46,47].

Umbilicaria saviczii occurs in the continental Antarctic[1,2]. This species is likely to be found in the examined area.

Umbilicaria aff. *thamnodes* was reported only from Charcot Island and Alexander Island[2]. Probably this Himalayan species should be found in other localities in Antarctica.

Species distribution

The species of *U. africana* and *U. aprina* are documented from the studied region for the first time. The occurrence of *U. antarctica U. decussata, U. kappenii, U. nylanderiana* and *U. umbilicarioides* in the Argentine Islands–Kyiv Peninsula region is confirmed. The occurrence of *Umbilicaria* species in the study area was briefly discussed above. The complete list of records with notes on local distribution for all *Umbilicaria* species recorded in the Argentine Islands–Kyiv Peninsula region and some new registrations outside this region is given in Appendix 1S. The maps of species distribution are provided in Figs. 3, 4, 5, 6, 7, 8 and 9.

Umbilicaria africana

It is reported for the first time from the area investigated in the present study. The species turned out to be rare and was found in only two localities, including Galindez and Skua Islands (Fig. 3, Appendix 1S). The discovery of the sites of *Umbilicaria africana* in the studied region makes it possible to shift the southern limit of its distribution in the maritme Antarctic about 300 km southward to the Argentine Islands region. On both islands, the occurrence of *U. africana* was restricted to the sheltered north-facing volcanic rock slopes where it was found outside the splash zone at an altitude of ca. 20–40 m a.s.l. The species was generally growing together with *U. kappenii, U. umbilicarioides*, and other fruticose and crustose lichens.

Umbilicaria africana is known from the high mountains of East Africa, where it occurs at altitudes between 3000 and 5000 m a.s.l.[48], from South America where it is often the most common high alpine *Umbilicaria* species found along the entire Andean Mountain Range from Venezuela to Chile at elevation between 4300 and 5000 m a.s.l.[35,36,49–52], and from Antarctica[1,2,4]. Moreover, *U. africana* has also been reported from Mt. Adjuno in Java[46]. However, as noted by Wei and Jiang[46], these specimens exhibit morphological inconsistencies with the species' original description. Therefore, their identification is only provisional and requires more detailed taxonomic evaluation. This type of disjunction distribution pattern, excluding Australia and New Zealand, is exceptional for lichens of the Southern Hemisphere and suggests that this species may represent an ancient phytogeographical element developed in the western regions of Gondwana[4].

In Antarctica, *U. africana* has been found in both the maritime Antarctic region, where it was reported from Livingston Island[4] and King George Island[1,44], and the continental Antarctic in the northern Victoria Land and Wilkes Land[4]. It has also been found in the Subantarctic in South Georgia[2,9]. The species seems to be rare, though

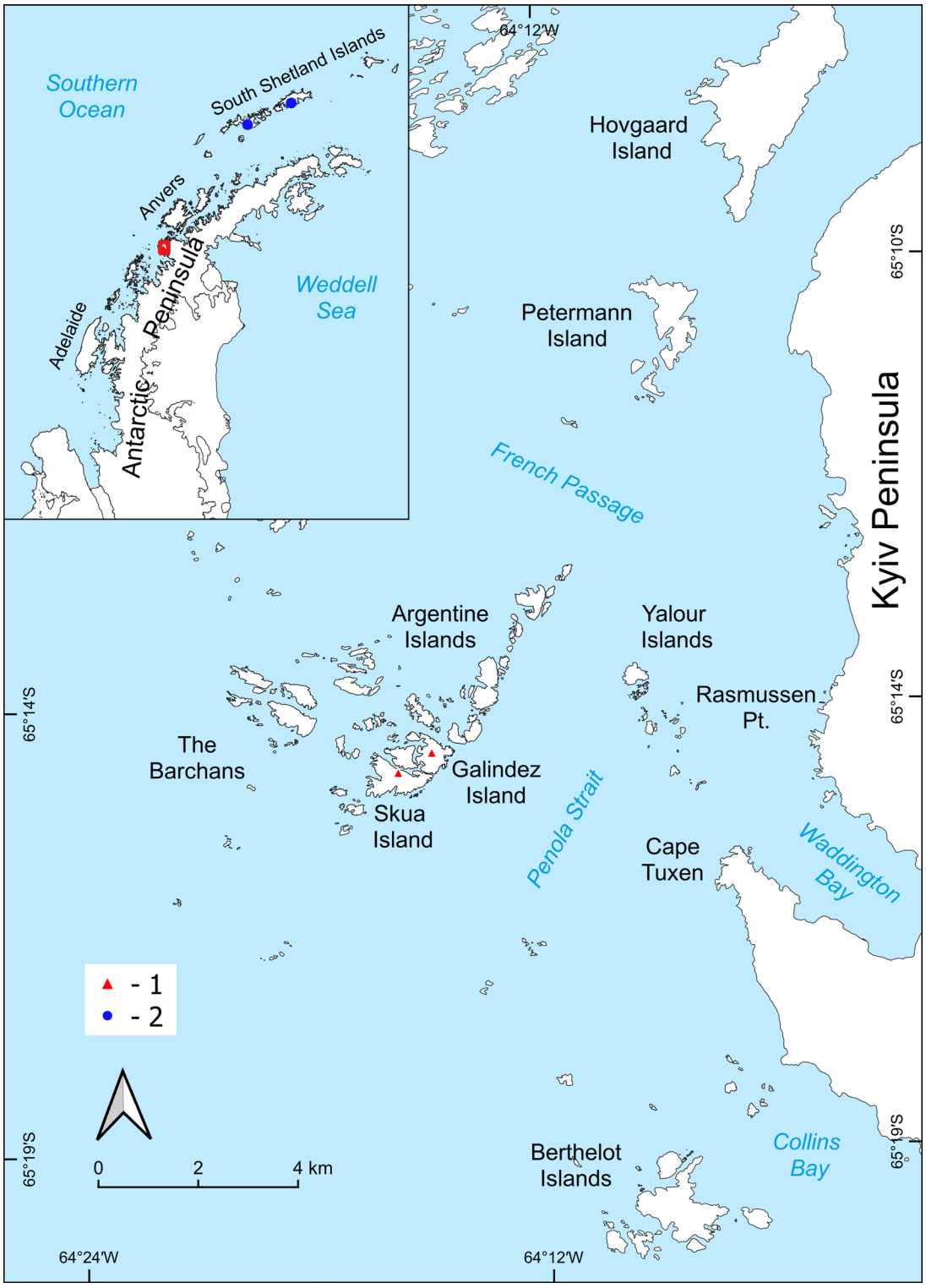

Figure 3. Map of the distribution of *Umbilicaria africana* in the region of the Antarctic Peninsula and the Argentine Islands–Kyiv Peninsula region: 1—new data, 2—previously recorded.

locally abundant[1], and usually found inland at elevations 25–200 m a.s.l.[4,44] on vertical, north-facing rocks, growing among other species of the genus[1].

Umbilicaria antarctica

From the Argentine Islands–Kyiv Peninsula region, the species was reported as abundant and frequent[7,8] and recorded at many sites, including Black Island, Galindez Island, Petermann Island, Uruguay Island, Rasmussen Island, the Berthelot Islands (with Green Island), Booth Island, Cape Tuxen and two continental points near

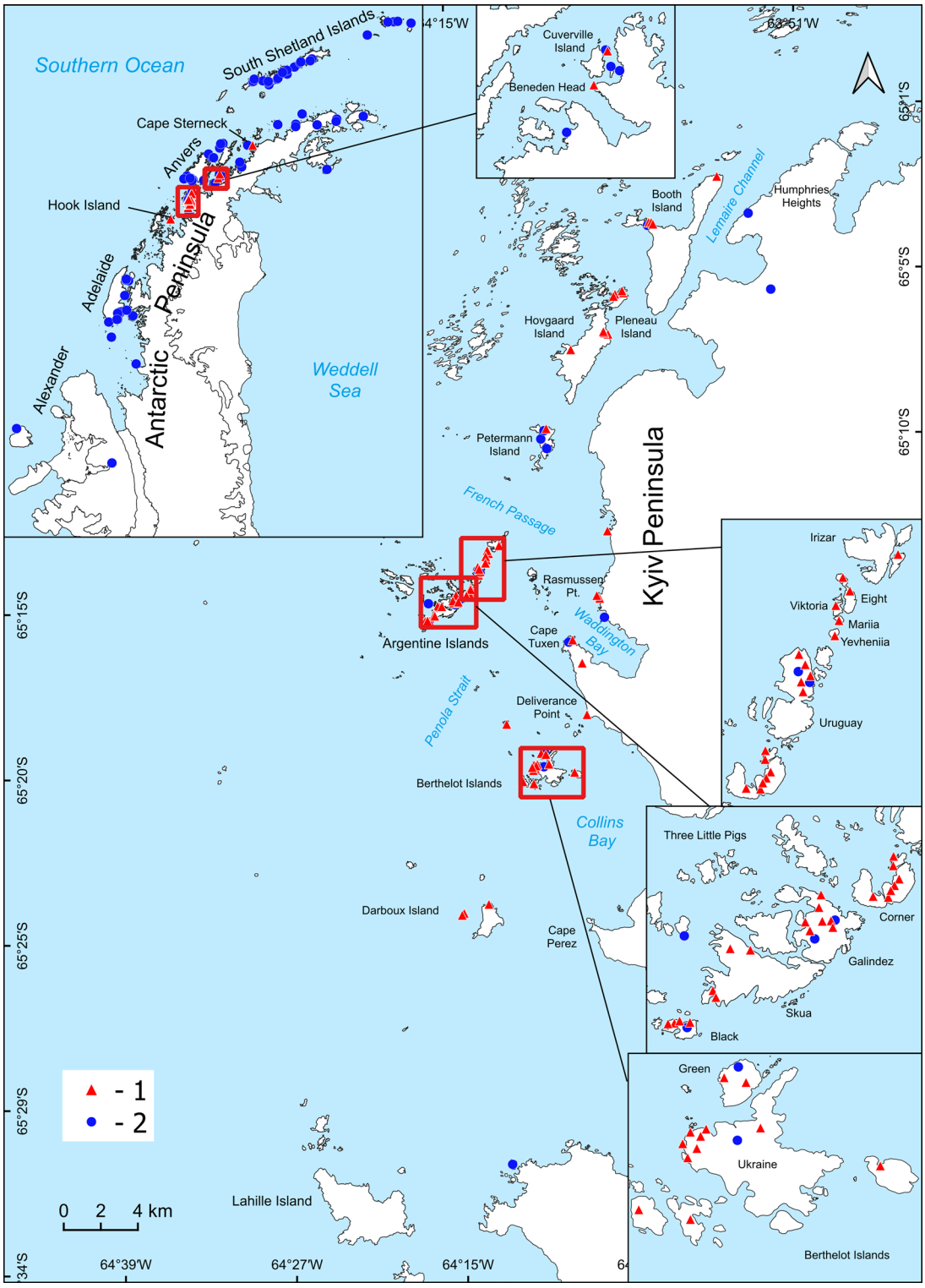

Figure 4. Map of the distribution of *Umbilicaria antarctica* in the region of the Antarctic Peninsula and the Argentine Islands–Kyiv Peninsula region: 1—new data, 2—previously recorded.

Lemaire Channel[9]. Our current study confirmed most of the previous reports from the Argentine Islands–Kyiv Peninsula region and added some new distribution records, including from other areas such as Beneden Head and Cape Sterneck on the Danco Coast or Hook Island on the Graham Coast (Appendix 1S). With a total of 68 recorded sites (including 36 new records), *U. antarctica* is the most common and widespread *Umbilicaria* species in the region (Fig. 4).

The species is particularly abundant in coastal sites on sheltered, north-facing moist boulders or cliff faces, where it often provides almost complete cover. It is found on a variety of volcanic and/or intrusive rocks at

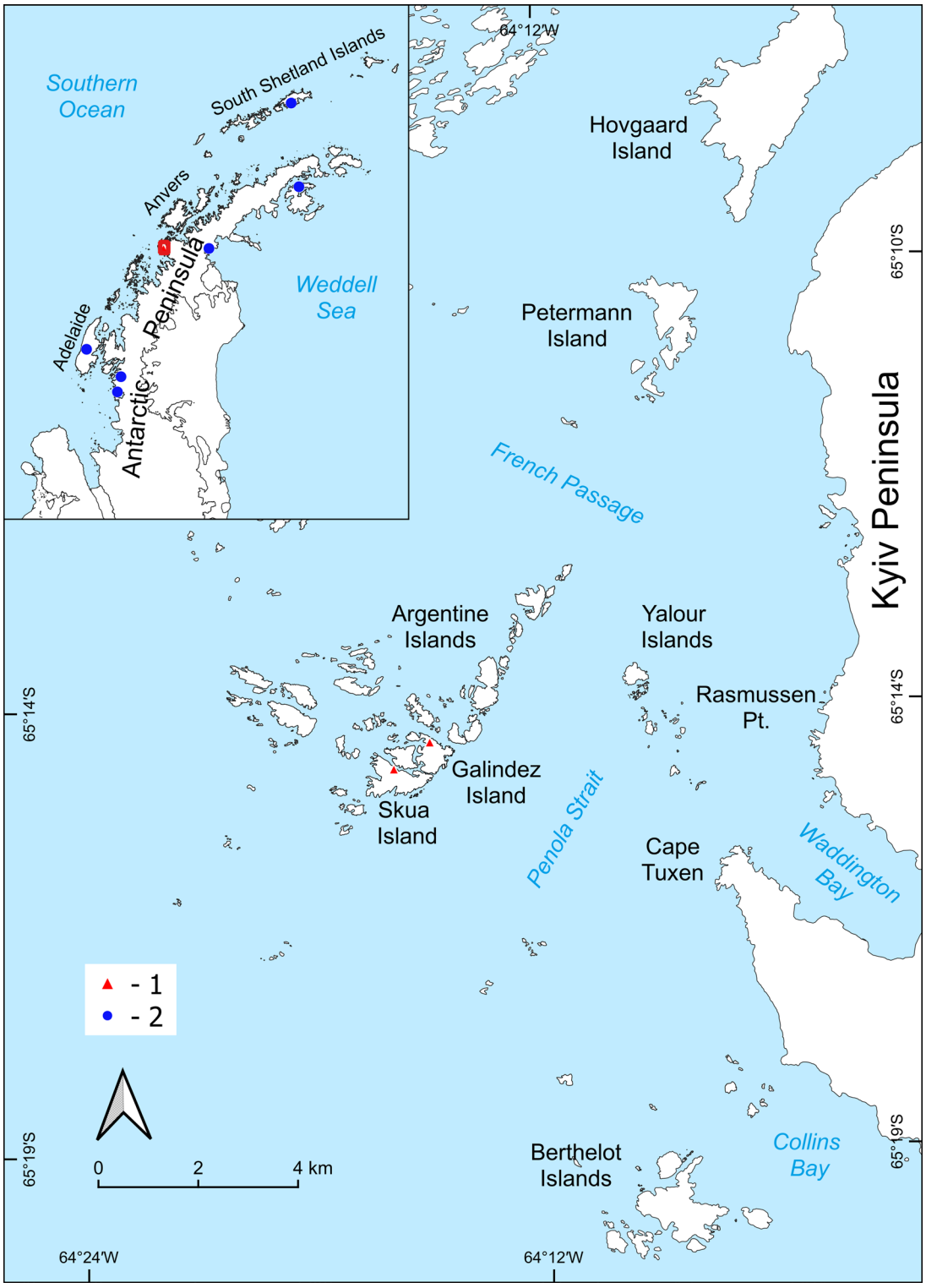

Figure 5. Map of the distribution of *Umbilicaria aprina* in the region of the Antarctic Peninsula and the Argentine Islands–Kyiv Peninsula region: 1—new data, 2—previously recorded.

altitudes 6–500 m a.s.l. However, it has an irregular range (Fig. 4, Appendix 1S). It does not occur in the splash zone and on the low outer islands, such as Cruls, Roca and Anagram, which are exposed to strong winds and extensive sea spray during storms. It also does not occur in areas exposed to ornithogenic influence, such as Great Yalour Island, which indicates its nitrophobic preferences. Typically grows with *Usnea antarctica*, alone or with other species of *Umbilicaria*.

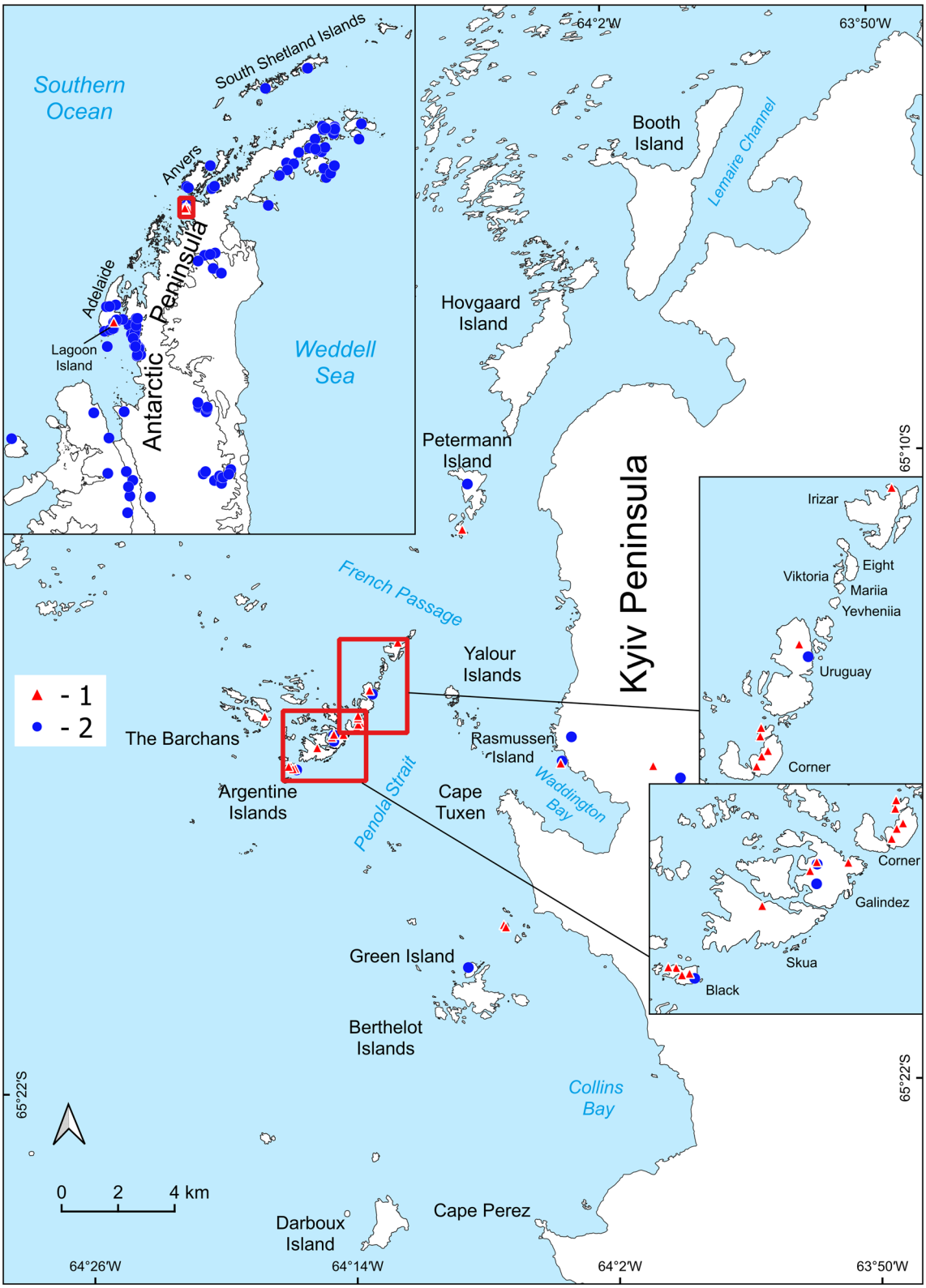

Figure 6. Map of the distribution of *Umbilicaria decussata* in the region of the Antarctic Peninsula and the Argentine Islands–Kyiv Peninsula region: 1—new data, 2—previously recorded.

This is an Antarctic endemic known previously as *U. rufidula* (Hue) Filson, the synonym name. The species is widely distributed and locally abundant, particularly across the northern maritime Antarctic, including the South Sandwich Islands, the South Orkney Islands, the South Shetland Islands and the Antarctic Peninsula[1,2], but only rarely found in the continental Antarctic[2,53].

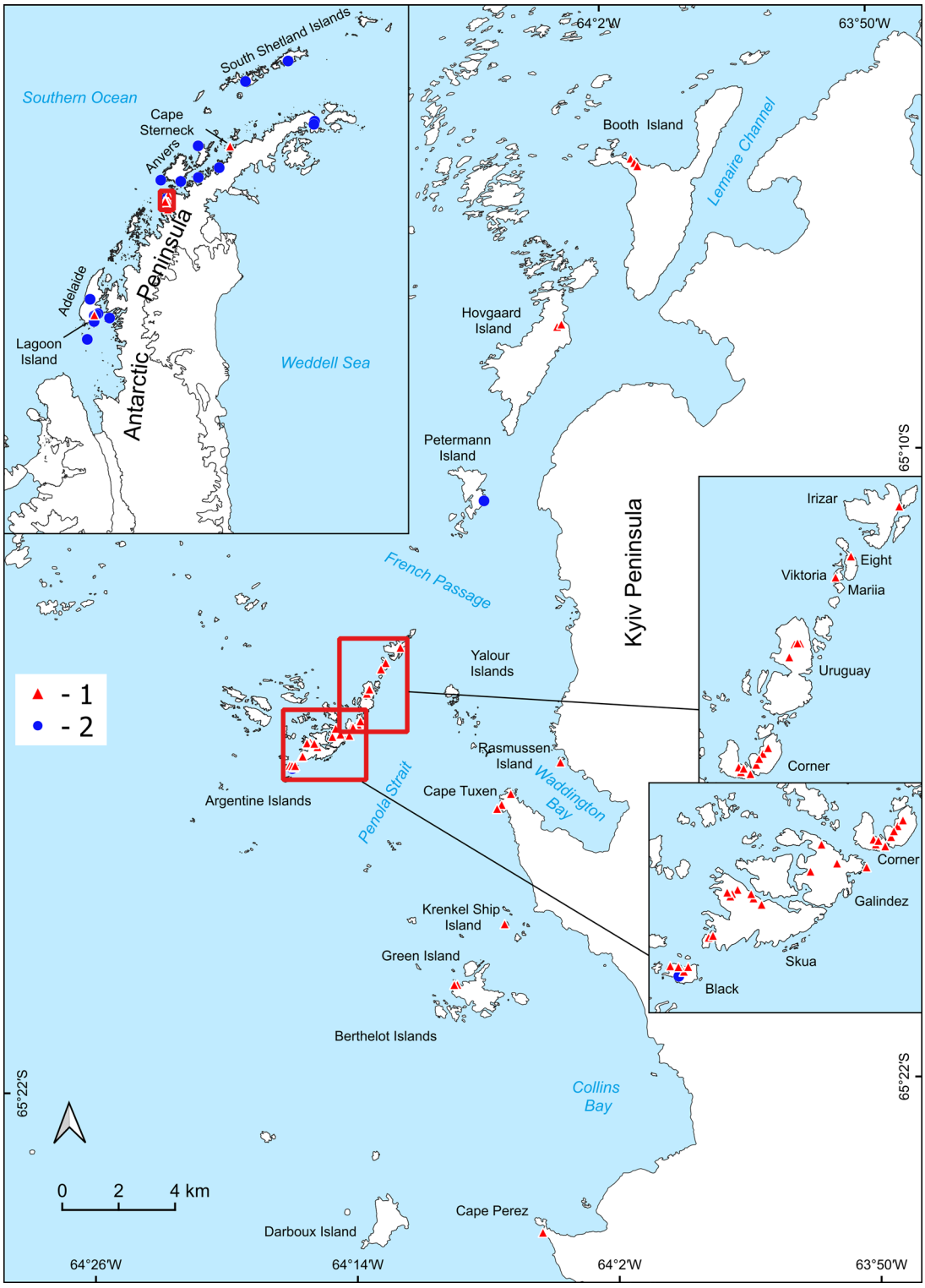

Figure 7. Map of the distribution of *Umbilicaria kappenii* in the region of the Antarctic Peninsula and the Argentine Islands–Kyiv Peninsula region: 1—new data, 2—previously recorded.

Umbilicaria aprina

Our current work provides the first documented records of *U. aprina* in the Argentine Islands–Kyiv Peninsula region. Though it has been reported nearby, from a few sites along the west coast of the Antarctic Peninsula[40], unfortunately exact locations of these collections are unknown. In the investigated area *U. aprina* appears to be rare, and was found only on two of the largest Argentine Islands, i.e.: Galindez and Skua Islands (Fig. 5). On both islands the occurrence of *U. aprina* was restricted to the coastal sites where it was found outside the splash zone at an altitude of ca. 16–20 m a.s.l., on rather dry sheltered north-facing volcanic rock outcrops. However, none

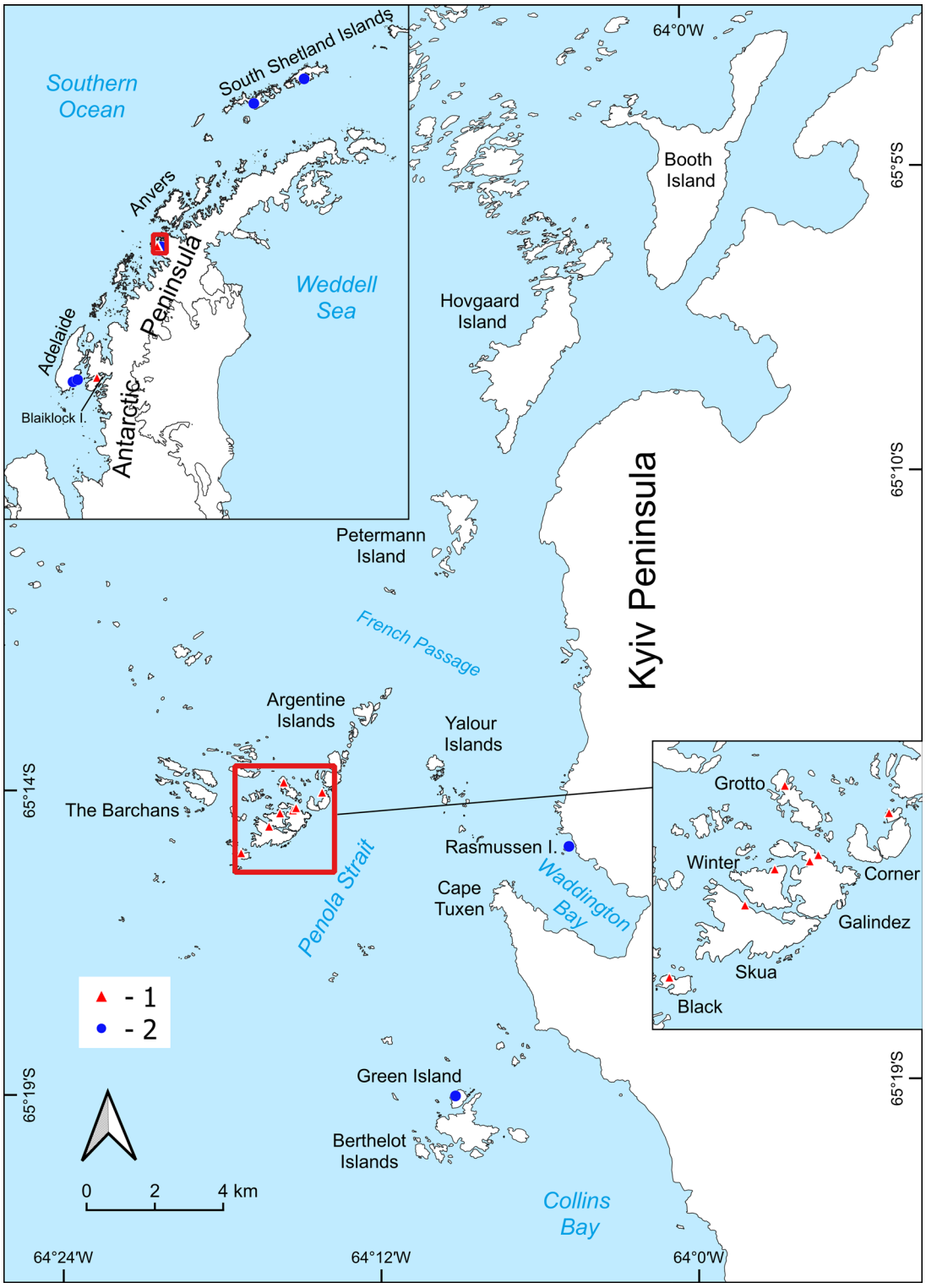

Figure 8. Map of the distribution of *Umbilicaria nylanderiana* in the region of the Antarctic Peninsula and the Argentine Islands–Kyiv Peninsula region: 1—new data, 2—previously recorded.

were found in habitats flushed by meltwater or at margins of temporary melt streams, indicated previously[2] as its typical habitat. The species was found growing together with other species of the genus, notably: *U. antarctica, U. kappenii, U. nylanderiana, U. umbilicarioides,* and other fruticose and crustose lichens.

Umbilicaria aprina is a species with disjunct bipolar-alpine distribution, it occurs in both Polar Regions and is also known from the high mountains across all continents except Australia[2,48,54]. However, for a long time, *U. aprina* was known only from Dedschen Mts. in Ethiopia, it was recorded at 4700 m a.s.l.[55] and from Ruwenzori Mts. in Uganda[56]. It was, therefore, considered as an African endemic. Later it was found in Scandinavia[57] and

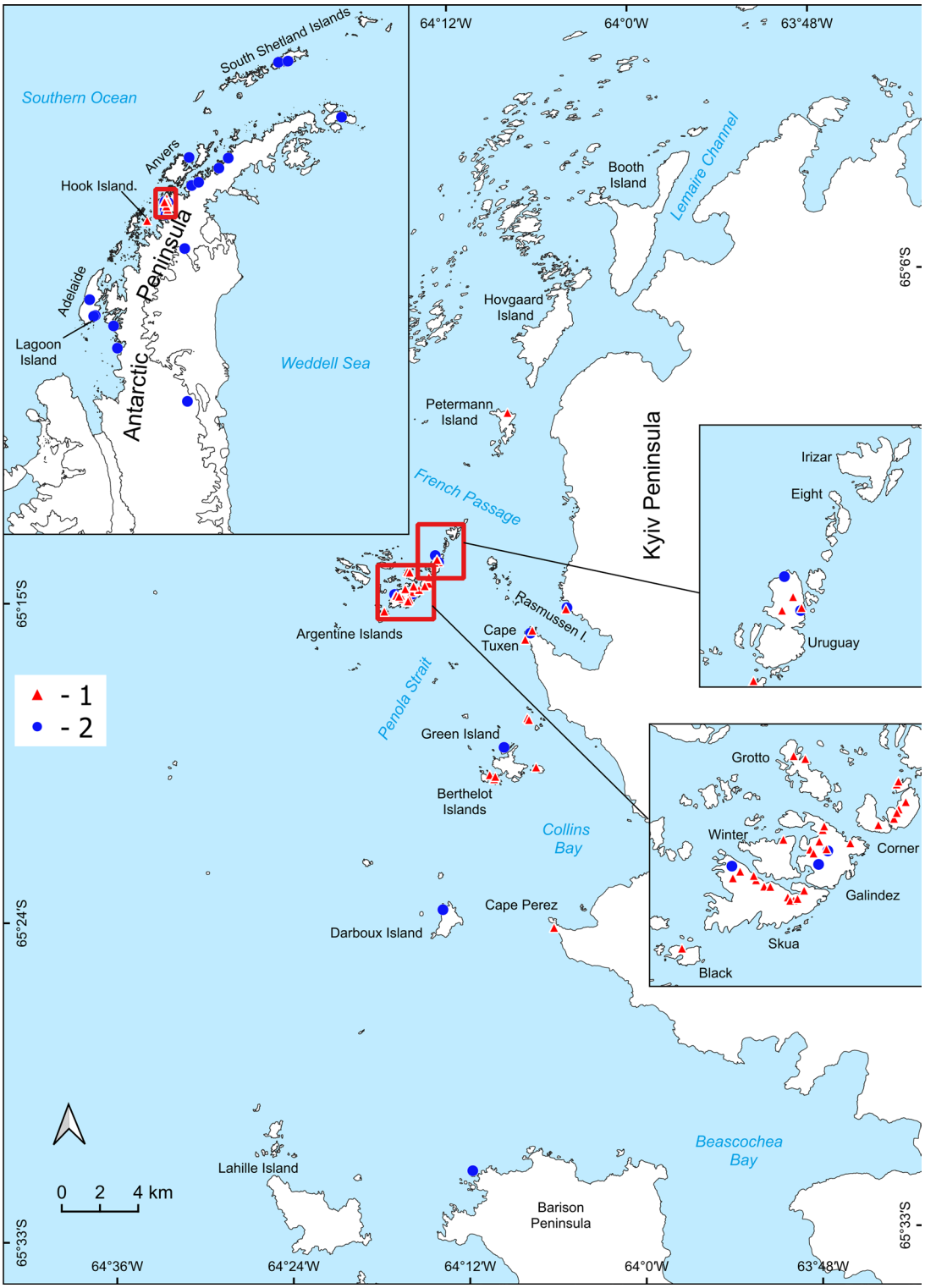

Figure 9. Map of the distribution of *Umbilicaria umbilicarioides* in the region of the Antarctic Peninsula and the Argentine Islands–Kyiv Peninsula region: 1—new data, 2—previously recorded.

in the American Arctic region[58,59]. Subsequently, it was also recorded across the Arctic region of Eurasia[59–63], in the Himalayans[64] and in high mountains of Europe, including the Alps[65], Carpathians[66] and Pyrenees[67] in South America along the Andes[35,36,51,68] and again in Africa on Kilimanjaro[48].

In Antarctica, *U. aprina* is known mostly from the continent, where it is widespread and locally abundant[2,4,40], with records spanning elevation between 10 and 1700 m a.s.l.[2]. On the other hand, in the maritime Antarctic, it seems to be rare and some of its previous records from King George and Livingston Islands, the maritime

Antarctic[69], are doubtful[2,4]; however, the occurrence of *U. aprina* on King George Island was confirmed in our previous treatment[1].

Umbilicaria decussata

From the Argentine Islands–Kyiv Peninsula region *U. decussata* has been reported as frequent, associated with gently sloping to vertical and dry wind-exposed rocks[7,8] and was found at several collection sites, including Black Island, Galindez Island, Petermann Island, Rasmussen Island, Green Island (the Berthelot Islands), Uruguay Island, Cal between Mt. Mill and Mt Balch and the Mount Mill summit[9]. During the present study, *U. decussata* was confirmed to be relatively frequent and locally abundant, and was recorded at 21 surveyed localities (12 new) of the studied region and 1 previously unknown site outside this region—Lagoon Island at Fallières Coast (Fig. 6, Appendix 1S).

In line with previous reports[1,2,4], *U. decussata* was found growing on wind-exposed dry rocks and cliff faces, predominantly on volcanic but also intrusive substratum (e.g. Boudet Island), and within broad altitudes ranging from low-elevation coastal sites (e.g. Boudet Island, 5 m a.s.l.) to inland high elevation sites (i.e. Gaies Cliff, 545 m a.s.l.). However, it does not occur on the low outer islands, such as Cruls, Roca and Anagram Islands, which are exposed to strong winds and extensive sea spray during storms. It was also not found on Great Yalour Island and the southern part of Petermann Island, hosting large penguin colonies and exposed to intensive ornithogenic fertilization. Observations from the Arctic[38] and New Zealand[37] suggest, however, that moderate ornithogenic fertilization provided by perching flying birds may provide favourable conditions for the species' growth. The species grows alone or with other species of the genus and other fruticose and crustose lichens.

Umbilicaria decussata is a cosmopolitan, distinctly high alpine species. It is widespread across, both the Northern and Southern Hemisphere, with distribution spanning all the continents and both Polar Regions, it is generally known only from scattered localities. For instance, in South America it occurs at altitudes 4500–5300 m a.s.l. along the entire Andean chain from Patagonia to Venezuela[35–38,49–51] but nowhere is common or abundant. In Australia, it was found only in the south-western territories along the Australian Alps and in Tasmania, where it is rare with the local population represented by only a few small thalli growing on exposed rock ridges that serve as bird perching sites[37]. In Europe, this species is known from all high mountain ranges but also nowhere is common or abundant[39], except for Svalbard where it is a common species[45,62]

On the other hand, in Antarctica this is a generally common and widely distributed species, growing on dry and exposed rocks from coastal sea level sites to high altitude far-inland sites at over 2000 m a.s.l.[1,2,70,71]. It is considered rare in the northern maritime Antarctic (i.e. South Orkneys and South Shetlands), and it becomes increasingly more common and abundant with increasing latitude, especially in the southern Antarctic Peninsula and around the Continent[2]. However, our previous survey on King George Island, South Shetlands[1], documented *U. decussata* as one of the most frequent species of the genus, and locally very abundant. Moreover, also in the area of Arthur Harbour (Antarctic Peninsula), it seems to be relatively common[7,8]. Thus, the view on latitudinal abundance pattern for *U. decussata* may not reflect the real distribution, but this could be mainly due to lack of floristic exploration and paucity of data.

Umbilicaria kappenii

Accordingly, in the Argentine Islands–Kyiv Peninsula region this species was previously reported only from Black and Petermann Islands[5,9]. Thus, a total of 45 localities of the Argentine Islands–Kyiv Peninsula region (41 previously unknown) and two outside this region (including a new record from Cape Sterneck) documented during our current study (Fig. 7, Appendix 1S) change considerably perception of the species occurrence in the area; *U. kappenii* appears to be one of the most common and abundant species of the genus. It is remarkable that only *U. antarctica*, generally recognized as the most common and abundant species of *Umbilicaria* across the entire maritime Antarctic[1,2], was recorded more frequently and at more sites during our survey. This finding is in line with previous studies[1,5] suggesting that *U. kappenii* is probably much more frequent and abundant across the maritime Antarctic, but is often overlooked in the field due to its high resemblance to *U. antarctica*.

While *U. kappenii* is widespread and often very abundant in the area, and growing both on volcanic and intrusive rocks (i.e. Rasmussen Island), similarly to other species of the genus, its occurrence is generally limited to sheltered north-exposed rock walls. Moreover, its distribution in the area appears to be restricted to coastal sites within altitudes of 3–80 m a.s.l. and, in contrast to reports from other areas[5,44], it was not found at higher elevations and sites distant from the coastline. The species was also not found on the low outer islands, such as Cruls, Roca and Anagram Islands, that are exposed to strong winds and extensive sea spray during storms. The lack of the species on Great Yalour Island and other areas exposed to strong ornithogenic influence indicates its nitrophobic preferences. Surprisingly, this taxon was reported previously from the southern part of Petermann Island[9] which hosts large penguin colonies. However, this record was not confirmed during our study.

Umbilicaria kappenii typically grows alone or mixed with other species of the genus, notably with *U. antarctica* and/or *U. umbilicarioides* (rarely also with *U. nylanderiana* or *U. africana*), and other fruticose and crustose lichens[7,8]. The co-occurrence of *U. kappenii* with *U. antarctica* is particularly noticeable, both species were often found together growing in intermixed stands, suggesting very similar ecological preferences for these two Antarctic endemics. However, with occurrence spanning the entire Antarctic and altitudes up to 750 m a.s.l.[2], *U. antarctica* demonstrates a considerably broader range of ecological and geographical distribution.

Umbilicaria kappenii is an Antarctic endemic with occurrence restricted to the maritime Antarctic. It appears to have a continuous distribution range throughout the entire region, extending from the South Orkneys in the north, along the west coast of the Antarctic Peninsula and its offshore islands, to as far south as Adelaide and Lagoon Islands (68°S)[1,2,5]. It also seems to have a relatively broad altitudinal range growing between 2 and 300 m a.s.l., though most commonly found on dry north-facing rocks in coastal areas[2,5]. However, despite its seemingly

wide altitudinal and latitudinal distribution range across the entire maritime Antarctic the species seems to be rare. For instance, during our previous survey on King George Island[1] it was found only in two sites. Similarly, Olech[44] despite long long-lasting and detailed survey of the same area reported only two additional sites.

Umbilicaria nylanderiana

In the Argentine Islands–Kyiv Peninsula region *U. nylanderiana* was previously recorded from the Argentine Islands–Galindez Island?[8], Rasmussen Island and probably Green Island[9]. Consistently, during our survey, the species was found to be rare and never abundant, and was recorded only at seven surveyed sites (probably five previously unknown) in the Argentine Islands–Kyiv Peninsula region, including Black, Galindez, Grotto, Skua, Storozh and Winter Islands, as well as at one previously unknown site, i.e. to the south of the studied area on Blaiklock Island on the Fallières Coast (Fig. 8). It was found only in coastal sites at altitudes of 8–20 m, growing on north-facing walls of different heights, on both volcanic and intrusive rocks. Its occurrence was typically associated with other species of the genus, notably with *U. umbilicarioides* and *U. kappenii*, and only rarely with *U. decussata, U. antarctica* or *U. aprina*, and fruticose and crustose lichens. However, as *U. nylanderiana* can be easily overlooked in the field due to its strong resemblance to *U. decussata* and *U. krascheninnikovii*[1,4], it is likely to be more frequent and future surveys may provide additional records.

This is a bipolar and high alpine species known from the mountain, polar and sub-polar habitats across all the continents, except Africa. While its distribution was primarily associated with the Northern Hemisphere, where it is generally common and widespread[4,39], recent surveys demonstrated its widespread distribution also across the Southern Hemisphere, including South America where it was found along the entire Andean chain at altitudes ranging between 4100 and 5300 m a.s.l.[35,36,49–51,72], in the Australian Alps and Tasmania above 1000 m a.s.l.[37] and the Southern Alps in New Zealand[73].

In Antarctica distribution of *U. nylanderiana* is restricted to the maritime Antarctic, with very few records scattered from the South Orkneys in the north[2,9], across South Shetlands[1,4,44] and the west coast of the Antarctic Peninsula and its offshore islands, to as far south as 68°S in Marguerite Bay on Léonie Island and Rothera Point on Adélaide Island[2,9]. It was found only in coastal sites at elevations between 5 and 200 m a.s.l., growing on ridges and vertical or sloping north-facing volcanic rocks, often together with *U. decussata*[1,4,44]. Although, generally rare and known only from very few sites it is locally abundant with populations in some environments more numerous than other *Umbilicaria* species[2,4].

Umbilicaria umbilicarioides

In the Argentine Islands–Kyiv Peninsula region *U. umbilicarioides* was previously reported as a frequent and locally abundant component of vegetation on Galindez Island[7,8]. Additionally, it was recorded only in a relatively few sites, including Galindez, Uruguay, Rasmussen, Skua and Green Islands, and Cape Tuxen[9].

During the current study, *U. umbilicarioides* was widespread and was recorded also at several other sites across the entire Argentine Islands–Kyiv Peninsula region (Fig. 9, Appendix 1S). Thus, currently with a total of 45 sites (19 previously unknown) recorded in the studied region, *U. umbilicarioides*, along with *U. antarctica* and *U. kappenii*, appear to be one of the most widespread and frequently recorded species of the genus. However, despite the broad distribution of *U. umbilicarioides*, it was not found on the low outer islands, such as Cruls, Roca and Anagram Islands, that are exposed to strong winds and extensive sea spray during storms. It was also not found on Great Yalour Island and the southern part of Petermann Island hosting large penguin colonies and exposed to intensive ornithogenic fertilization. Thus, the local distribution of *U. umbilicarioides* appears to be confined to more sheltered coastal sites and altitudes between 3 and 42 m a.s.l., where it was found growing on sheltered north-facing walls of different heights, on both volcanic and intrusive substratum. It grows alone or with other *Umbilicaria* species, notably with *U. antarctica* and less frequently with other species of the genus. We also found a new stand of *U. umbilicarioides*, on Hook Island south of the studied region.

Specimens of this species were previously reported from Antarctica as *U. propagulifera* (Vain.) Llano which is currently treated as a synonym name of *U. umbilicarioides*. Its distribution seems to be confined to the Southern Hemisphere, where it has been reported from alpine and subalpine environments in South America[38], Africa[48], Australia[37], New Zealand[72] and Antarctica[1,2]. In some previous treatments *U. umbilicarioides* was considered as having bipolar-alpine disjunct distribution, but the records from Northern Europe were mistakenly reported as *U. propagulifera*[74,75]; according to Hestmark[76], they actually represent the species *U. dendrophora* (Poelt) Hestmark. However, for some *Umbilicaria* specimens from the Carpathian Mountains in Romania and Poland, initially determined based on their morphology as *U. cylindrica* group (without thalloconidia), their sequences in molecular analyses (ITS and LSU) were unexpectedly claded together with sequences of *U. umbilicarioides* from Antarctica[77]. Thus, the occurrence of *U. umbilicarioides* in the mountains of the Northern Hemisphere should still be considered.

In Antarctica, the distribution of *U. umbilicarioides* seems to be restricted to the maritime Antarctic and the Subantarctic. Although it has also been reported from Enderby Land in the continental Antarctic, this record is dubious[2]. Thus, the known distribution of *U. umbilicarioides* spans numerous records scattered from South Georgia[9], South Orkneys[2,9], South Shetlands[1,43,78] and many sites along the west coast of the Antarctic Peninsula and its offshore islands, to as far south as 69.5° S on Engel Picks at Wilkins Coast[9]. Although locally frequent and abundant, especially on dry rocks and pebbles on raised beaches in the mid-southern Antarctic Peninsula, e.g. in northern Marguerite Bay, is generally considered rare[2].

Possible local dispersal mechanisms

Umbilicaria species are not evenly distributed in the study area (Figs. 3, 4, 5, 6, 7, 8 and 9). It is not clear what the reason for this distribution is, but there are two main factors in the spread of diasporas—wind and birds[79,80].

The species of this genus reproduce mainly by producing vegetative propagules such as soredia, isidia, thalloconidia, conidia or thalli fragmentation and thallyles, whereas production of generative spores is very rare on this area[38,67,81]. Propagules are likely carried here mainly by the wind. In winter they are transported between islands through frozen channels, while in summer they move mainly within neighbouring islands. This is evidenced by the local distribution of these species, which is concentrated in the coastal zone.

The birds are the second factor in the dispersal of diasporas in this area. The fragments of *Umbilicaria* specimens were discovered in nests of *Stercorarius maccormicki* on Winter, Grotto and Skua Islands, and in nests of *Larus dominicanus* on Galindez Island, on the north part of Petermann Island and Booth Island. The fragments of the thallus of *Umbilicaria antarctica* (KRAM-L 70414) and *Umbilicaria kappenii* (KRAM-L 72656) were discovered in nests of *Larus dominicanus* located on the northern coast of the eastern arm of Booth Island. The nearest site of both species was several dozen meters higher on the slope. In addition, birds could collect fragments of the *Umbilicaria kappenii* thallus on the top of the ridge of the eastern arm of Booth Island, where this species grew on rocks (KRAM-L 72403). Whereas the thalli of *Umbilicaria antarctica* could be collected by birds 4 km to the northeast on the northern head of Booth Island in a green oasis where birds also collected rare moss *Warnstorfia sarmentosa* (Wahlenb.) Hedenäs for nest building. This moss species occurs only in this one place in this part of the region. In the case of birds, species with more noticeable thalli may have an advantage in transport. This would explain the wide local range of the species with the largest sizes, such as *U. antarctica* and *U. kappenii* (Figs. 4 and 7). Birds also use lichen thalli for mating behaviour. At the beginning of the summer season, fragments of lichen thallus abandoned by gulls during the mating season are regularly recorded near the Vernadsky station on Galindez Island. Specimens of lichens abandoned by birds can be next transported by the wind. In the region, probably both dispersal mechanisms of foliose lichens are important.

Conclusions

Our study demonstrates that the Argentine Islands–Kyiv Peninsula region is characterized by a relatively high diversity of the *Umbilicaria* species (7 taxa).

Umbilicaria africana and *U. aprina* were recorded for the first time in the region. The discovery of the species *U. africana* here shifts the southern limit of its distribution by approximately 300 km south.

Umbilicaria antarctica is the most frequent species in the region. This taxon is a dominating species in the maritime Antarctic. *Umbilicaria umbilicaroides* which was until now treated as rare in Antarctica is widely distributed in the study area. It is one of the most numerous species in this area, along with *U. antarctica* and *U. kappenii*.

Umbilicaria decussata is a widespread species in the maritime Antarctic, however, it is less frequent in the study area. It was also discovered on an inland nunatak on the Kyiv Peninsula—the next registration of this species inland in this Peninsula region.

Umbilicaria nylanderiana is a rare species in this region. During the current study, it was found exclusively on the Argentine Islands.

Data availability

The voucher specimens were deposited in the Herbarium of the W. Szafer Institute of Botany Polish Academy of Sciences in Krakow (KRAM L), Lubicz 46, 31-512 Kraków, Poland. The thallus material for nuclear ITS rDNA sequence analysis was obtained from 18 specimens of *Umbilicaria* (GenBank accession numbers PP580112, PP580129).

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Conceptualization—B.K., I.P., J.S.; Methodology—B.K., I.P.; Validation—B.K.; Formal Analysis—B.K., I.P.; Investigation—I.P., V.I.; Data Curation—B.K.; Writing–Original Draft Preparation—B.K., I.P.; Writing–Review and Editing, B.K., I.P., J.S., V.I., H.Y.; Visualization B.K., H.Y.; Supervision—B.K.; Project Administration—I.P.; Funding Acquisition I.P.,B.K., J.S.; ALL authors have read and agreed to the published version of the manuscript.

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Competing interests

The authors declare no competing interests.

Additional information

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