Current status of the freshwater red algal diversity (Rhodophyta) of the African continent including description of new taxa (Batrachospermales)

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Running title: Freshwater Rhodophyta diversity in Africa

ABSTRACT

Freshwater red algae have been collected on the African continent since the early 1800s. However, the collections have been sparse and geographically restricted. The present study sought to bring together information from the literature, herbarium specimens and newly collected specimens to provide an updated assessment of the freshwater red algal diversity of the African continent with a focus on the species rich Batrachospermales. DNA sequence data and morphological observations were conducted for recently collected specimens. From these analyses, four new taxa are proposed: *Kumanoa bouwmanii, Sheathia murpheyi, Sirodotia kennedyi* and the form taxon '*Chantransia azurea*'. DNA sequence data had been previously published for *Kumanoa iriomotensis*, *Sirodotia* aff. *huillensis* and *S. suecica*. With this study, we have added sequence data for *Torularia atra* as well as a second location for *S. suecica*. In total, there are eight taxa with sequence data, of which five appear to be endemic. From our assessment of literature reports and herbarium specimens, we conclude that *Kumanoa*, *Sirodotia* and *Torularia* have often been collected and are relatively geographically widespread with two or more species present. In addition, *Montagnia*, *Nothocladus*, *Paralemanea*, *Sheathia* and *Visia* as well as *Batrachospermum* section *Gonimopropagulum* are represented in the flora. We estimate that 14 to 19 batrachospermalean taxa can be recognized for the African flora, and that with more study, that number could easily double or triple based on the diversity known from other well-studied continents.

KEY WORDS Africa; Batrachospermales; Biogeography; COI-5P; Freshwater red algae; *rbc*L gene; Molecular systematics; Morphology; Rhodophyta; Taxonomy

INTRODUCTION

Most members of the Rhodophyta are marine seaweeds, but there is a substantial number of taxa that inhabit freshwater and terrestrial environments (Kumano 2002). These freshwater and terrestrial red algae are classified in 14 orders (Kumano 2002; Guiry & Guiry 2019). Some orders have primarily marine members with a few taxa that have transitioned to freshwater habitats. For example, species of *Bostrychia* and *Caloglossa* in Ceramiales occur in estuarine habitats, but have been reported from strictly freshwater water habitats (Sheath *et al*. 1993, Johnston *et al*. 2014; West *et al*. 2015). *Audouinella* and *Ottia* are the only freshwater genera in the marine order Acrochaetiales (Entwisle *et al*. 2017; Saunders *et al*. 2018). In Hildenbrandiales, *Hildenbrandia* has both marine and freshwater species (Sherwood & Sheath 2003). There are only four orders in which all members are strictly freshwater: Balbianiales, Batrachospermales, Compsopogonales and Thoreales. Balbianiales, Compsopogonales and Thoreales all contain less than three genera, but the Thoreales has *c.*18 species with the others having three or fewer (Sheath *et al*. 1994; Necchi *et al*. 2013; Johnston *et al*. 2018). The bulk of species diversity for freshwater red algae is in Batrachospermales with approximately 140 species in 19 genera (Guiry & Guiry 2019).

Although freshwater red algae have been reported from a variety of habitats including specialized environments such as hot springs, the majority tend to inhabit streams and rivers, with fewer taxa in lakes and bogs (Sheath & Vis 2015). These environments have been examined and specimens collected from most continents (except Antarctica; Kumano 2002). Some continents, areas and regions have been well-studied. For example, there are recent floristic publications on Europe (Eloranta *et al*. 2011; Eloranta 2019), North America (Sheath & Vis 2015), the British Isles (Sheath & Sherwood 2011), and India (Ganesan *et al*. 2018). However,

there are still gaps in our knowledge. Vis (2016) used the Batrachospermales as a biogeographic case study to examine the distribution of *Batrachospermum* sections and genera among the continents. Only Australia had fewer taxa than Africa and it was hypothesized that the low numbers for Africa may have been due to lower sampling effort than the other continents (Vis 2016). Africa shared many of these taxa with other continents, but of note was *Nothocladus* sensu stricto that has only been reported from Africa and Australia and *Batrachospermum* section *Gonimopropagulum* which appears to be endemic (Vis 2016). This case study at the generic level provided some information on the African flora and its relationship with the flora of other continents, but a more in depth understanding of species diversity could yield more biogeographic insights.

The first records of freshwater red algae exclusive of specialized habitats (i.e. aerophytic, hot springs) from Africa come from the early to mid 1800's with species described by Bory (1808). More collections and species descriptions followed in the mid to late 1800s (Table 1). There were a handful of records published between 1900 to the 1960's and subsequently, there have been a few papers documenting freshwater red algae from parts of the continent (Table 1). Most taxa reported are from Batrachospermales (16), but there are records of some taxa in Acrochaetiales (2), Ceramiales (4), Compsopogonales (1), Hildenbrandiales (2) and Thoreales (1). Geographic records are most common from South Africa and the islands of Madagascar, Mauritius and Réunion, but reports from eleven countries are present in the literature (Table 1).

The order Batrachospermales, which comprises most of the taxon records for the African continent, has undergone substantial taxonomic change in recent years. Most of the sections of *Batrachospermum* have been raised to genera and there have been proposals for new genera and species (e.g. Entwisle *et al*. 2009; Salomaki *et al*. 2014; Necchi *et al*. 2019a, b). Prior to

93 establishment of *Kumanoa*, there were nine genera recognized in the order, whereas currently
94 there are 19 (Entwisle *et al*. 2009; Guiry & Guiry 2019). In addition, many recent studies used
95 DNA sequence data and showed that taxa previously thought to be widespread harbored cryptic
96 species with more restricted distributions (e.g. Salomaki *et al*. 2014; Necchi *et al*. 2019a, b).
97 Nevertheless, studies have also confirmed a few species, such as *Sirodotia suecica* Kylin, as
98 cosmopolitan, occurring on numerous continents (Lam *et al*. 2012). Most of the herbarium
99 collections and literature records from Africa occurred prior to this new taxonomy and would
100 benefit from updating the nomenclature as well as determining the identity of specimens using
101 recent taxonomic literature.
102 A study documenting the diversity of freshwater red algae in Africa would complement
103 research on other continents, provide a better understanding of the taxonomic diversity and
104 potentially offer valuable biogeographic insights. Therefore, this research was undertaken to
105 identify newly collected specimens and place them within the context of the known diversity on
106 the African continent and to use them to understand biogeographic trends in Batrachospermales
107 as well as individual species' distributions. When possible, specimens of Batrachospermales
108 from herbarium collections were accessed to verify taxon records and distributions. Although the
109 focus of the current study was primarily the Batrachospermales due to the diversity of taxa, the
110 literature for other freshwater red algal species (exclusive of extremophiles) was surveyed and
111 presented.
112

113 **MATERIALS AND METHODS**

114 Recent collections of specimens were made from 12 locations as follows: Nigeria (1), South
115 Africa (6), and Zambia (5) (Table S1; Fig. 1); these include three specimens with sequence data

previously published (Lam *et al.* 2012; Vis *et al.* 2012). Collections were pressed on herbarium sheets or dried in silica desiccant. A portion of each specimen was deposited in the Floyd Bartley Herbarium (BHO); specimens from South Africa and Zambia were also deposited in South African National Diatom Collection (SANDC), and those from Nigeria in the herbarium of the University of Lagos (LUH).

Morphological identifications of the recent collections were made to the lowest taxonomic level possible. Specimens were examined using a BX-40 compound microscope (Olympus America, Center Valley, Pennsylvania, USA) and SZ-40 stereomicroscope (Olympus America). Measurements and photomicrographs of morphological characters were performed using the cellSens program (Olympus America) and the microscope mounted SC-100 camera (Olympus America). Recent taxonomic literature was consulted including Kumano (2002), Lam *et al*. (2012), Necchi & Vis (2012), Salomaki *et al*. (2014) and Rosignolo & Necchi (2016). When possible, measurements of quantitative characteristics were made as follows: whorl diameter, fascicle cell number, carpogonium diameter/length/branch cell number, spermatangial diameter/length, carposporophyte diameter/length, carposporangial diameter/length and gonimoblast cell number. Qualitative characteristics of thallus color after drying, placement of the carposporophytes relative to the whorl, shape of whorls, trichogynes and fascicle cells as well as any other distinguishing features were noted.

For these recent collections, DNA sequence data were generated. A portion of the thallus was wetted and removed from herbarium sheets, placed in a 1.5 ml microcentrifuge tube with silica desiccant. Some specimens had been placed in desiccant in the field. The desiccated material was ground in liquid nitrogen using a mortar and pestle and processed using the Nucleospin Plant II DNA kit (Macherey-Nagel, Bethlehem, PA) according to manufacturer's

protocol. PCR was performed to amplify a 1282 base pair (bp) fragment of the chloroplast encoded rubisco large subunit gene (*rbc*L) and a 664 bp portion of the mitochondrial encoded *cox*1 gene (COI-5P). The primers used for *rbc*L amplification were F160 and *rbc*LR (Vis *et al*. 1998). When a PCR product was not obtained from this primer pair, the region was amplified as two separate fragments pairing F160 with R897.1 and F650 with *rbc*LR to achieve the same sequenced region (Salomaki *et al*. 2014). The primers used for COI-5P were GazF1 and GazR1 (Saunders 2005). The PCR master mix contained 19 µl of autoclaved deionized water, 1.5 µl of each primer and 2 µl of DNA with an Illustra™ PuReTaq Ready-To-Go PCR Bead (GE Healthcare, Pittsburgh, Pennsylvania, USA). The thermocycler settings for *rbc*L were as follows: 95 ˚C for 1 min, then 35 cycles of 93 ˚C for 30 sec, 50 ˚C for 30 sec, 72 ˚C for 1 min, and a final hold for 10 min at 72˚C; the settings for COI-5P were 95 ˚C for 1 min, 35 cycles of 93 ˚C for 30 sec, 50 ˚C for 30 sec, 68 ˚C for 1 min, and a final hold for 10 min at 72 ˚C. PCR products were purified using the PureLink™ Quick PCR Purification kit and sequenced at the Ohio University Genomics Facility. For the longer *rbc*L fragment, two internal primers F650 and R897.1 or R897 were used in the sequencing reactions to obtain full length sense and anti-sense strand sequence (Stewart *et al*. 2007). Sequence data were compiled using Sequencher™ v5.2.4 (GeneCodes Corp, Ann Arbor, Michigan, USA) and compared to published DNA sequences using the BLAST feature of GenBank (Benson *et al*. 2018). All new sequence data generated were submitted to GenBank.

For phylogenetic analyses, numerous data sets were created utilizing *rbc*L and COI-5P sequences data from GenBank. To examine the placement of the African specimens in Batrachospermales, 54 previously published specimens of Batrachospermales and 4 specimens of Thoreales were utilized with both *rbc*L and COI-5P data. There were two new specimens of

Sirodotia with only *rbc*L or COI-5P data, and all other specimens had both genes (Table S2). To examine the relationship of the African specimens with all species within *Kumanoa, Sheathia* and *Sirodotia*, *rbc*L data alone were utilized and single gene trees constructed since there are many fewer species with COI-5P data. For *Kumanoa*, all *rbc*L GenBank sequences were downloaded and a single sequence was used to represent each of the *Kumanoa* species with DNA sequence data; this resulted in 32 sequences including those generated in this study, as well as nine outgroup taxa for a total of 41 sequences. For *Sheathia*, all unique sequences for *S. arcuata* and at least one representative from the other *Sheathia* species were used. For *Sirodotia*, only unique *rbc*L sequences with more than 1000 bp were used. These data sets were analyzed using maximum likelihood (ML) implemented in RAxML (Stamatakis 2014) and Bayesian Inference (BI) implemented in MrBayes v.3.2 (Ronquist *et al*. 2012) as plug-ins in Geneious Prime 2019.2.1 (https://www.geneious.com). For ML and BI analyses, a GTR+G model was employed and support values were determined from 1000 ML bootstrap replicates and BI posterior probabilities of 3×10^6 generations sampling every 100 generations with the first 250 generated trees removed as burn-in.

Historical reports of freshwater red algae from Africa were investigated using a variety of data sources. Published literature was researched by keywords (algae, freshwater and Africa) in ISI web of science and the references in Kumano (2002) and Levanets & van Rensburg (2010). As well, records in an unpublished manuscript of M. Pocock were utilized (Table 1). Specimen names were updated to currently accepted taxonomy based on AlgaeBase (Guiry & Guiry 2019). Herbarium records for taxa in Batrachospermales and Thoreales from the Botanic Garden Meise (BR), Selmar Schonland Herbarium in South Africa (GRA), the Muséum National d'Histoire Naturelle in France (PC) and the herbaria consortium Macroalgal Herbarium Portal

(macroalgae.org accessed March 2019) were reviewed (Table 2). Specimens were requested from University of Michigan (MICH) and Harvard University (FH). When possible, herbarium specimens were examined microscopically and identified to the lowest taxonomic level possible similar to recent collections. If the specimens could not be microscopically examined only the nomenclature was updated.

RESULTS

DNA sequence analyses

Sequence data for the *rbc*L gene of specimens identified as *Kumanoa iriomotensis* (Kumano) M.L.Vis, Necchi, W.B.Chiasson & Entwisle, *Sirodotia* aff. *huillensis* (Welwitsch ex West & G.S.West) Skuja and *S. suecica* from Africa were previously published and new COI-5P data were generated for *Sirodotia* (supplemental Table S1). New sequence data for *rbc*L gene and COI-5P were generated for four more specimens. For two specimens, DNA sequence data from only one of the two regions were obtained. Unfortunately, no DNA sequence data were obtained for eight specimens after multiple attempts at DNA extraction and PCR. In total, DNA sequence data of *rbc*L are available for eight specimens and data of COI-5P for seven specimens (supplemental Table S1).

Phylogenetic analyses of the *rbc*L and COI-5P concatenated sequences using both ML and BI for specimens from Africa with sequence data and other batrachospermalean taxa showed similar tree topologies, and only the ML tree with support values is shown (Fig. 2). Specimens were placed in clades for *Kumanoa*, *Sheathia*, *Sirodotia*, and *Torularia* with high support values. However, one specimen of '*Chantransia'*, was on a long branch and sister to *Virescentia*, but this placement was only supported by posterior probabilities (Fig. 2). *Torularia atra* (Hudson)

M.J.Wynne from South Africa was sister to another specimen from Australia identified as *T. atra*.

Further ML and BI phylogenetic analyses were conducted for *Kumanoa*, *Sheathia* and *Sirodotia* using only *rbc*L sequences since there are data for more species than in the concatenated alignment (Figs 3-5). The ML and BI analyses of *Kumanoa* species and specimens from Africa showed similar tree topologies and only the ML with support values is shown (Fig. 3). The new species of *Kumanoa* was within a clade with *K. montagnei* Entwisle, M.L.Vis, W.B.Chiasson, Necchi & A.R.Sherwood and *K. nodiflora* (Montagne) Entwisle, M.L.Vis, W.B.Chiasson, Necchi & A.R.Sherwood with high support values. The other specimen, *K. iriomotensis* was sister to *K. curvata* (Z.-X.Shi) M.L.Vis, Necchi, W.B.Chiasson & Entwisle, but with low support in both analyses (Fig. 3). The ML and BI analyses for *Sheathia* species and the specimen from Africa showed similar tree topologies and only the ML with support values is shown (Fig. 4). The new species of *Sheathia* was within a large clade of specimens of *S. arcuata* (Kylin) Salomaki & M.L.Vis. This *S. arcuata* complex has specimens from worldwide locations and the sequence diversity is greater than other species of *Sheathia* (Fig. 4). The ML and BI analyses for *Sirodotia* species and specimens from Africa showed similar tree topologies and only the ML tree with support values is shown (Fig. 5). One specimen, *S. suecica*, was within a large clade of highly similar sequences of other specimens identified as *S. suecica*. *S.* aff. *huillensis* did not seem to be closely allied to any particular species (Fig. 5). The new species of *Sirodotia* was sister to a clade from South America identified as *S. delicatula* Skuja, but that relationship was only supported by posterior probability.

Morphological analyses

Both the specimens that had DNA sequence data and the specimens that did not yield those data were examined for microscopic characters that could be used for identification. The morphological data for those specimens identified as new to science using the DNA sequence data is provided in the taxonomic proposal section. The specimen recognized as *Torularia atra* via DNA sequence data had morphological characters consistent with that species; likewise, the specimen of *Sirodotia suecica* from Zambia was confirmed with morphology. The specimens of *Kumanoa iriomotensis*, *Sirodotia suecica* (South Africa) and *S.* aff. *huillensis* had been examined and confirmed in previous studies. The other eight specimens without sequence data were identified to the lowest taxonomic level possible with the morphological characters present (Table S1). Three of the specimens were identified as *Montagnia* cf. *macrospora* (Montagne) Necchi, M.L.Vis & A.S.Garcia based on overall gametophyte morphology and large carposporangia. Two specimens had the overall gametophyte morphology of *Visia*, but identification of species requires sequence data so they were labelled *Visia* sp. (Necchi *et al*. 2019a). One specimen was identified as *Sirodotia* sp. based on an asymmetrical carpogonium and an indeterminant carposporophyte; however, no spermatangia were observed in order to determine the species. A specimen of *Thorea* sp. was identified, but no reproductive structures were observed. A specimen with well-developed barrel-shaped whorls was identified as *Batrachospermum* sp. as it had spermatangia and a few carpogonia on undifferentiated carpogonial branches and regular cortication. However, this specimen could be *Sheathia* as some species do not have heterocortication.

When possible, the historical specimens were morphologically examined to confirm species identification and determine morphological characters that might warrant new taxon status. Specimens of *Batrachospermum africanum* Rabenhorst were examined from PC and FH.

These were determined not to be *Batrachospermum* and most likely not a red alga. Specimens were sought for *Batrachospermum bohneri* Schmidle from the most likely herbarium of deposit, Eidgenössische Technische Hochschule Zürich (ZT), but none were found. The description of *B. bohneri* and the subsequent paper devoted to carpogonial development note large carpospore size and enlarged pit connections between cells of the carpogonial branch (Schmidle 1899a, b). These characters would place it in the genus *Montagnia*, and most likely synonymous with *M. macrospora* as that species is known from South America and Asia (Necchi *et al*. 2019b). Specimens of *Batrachospermum patens* Suhr showed the overall gametophyte morphology of *Torularia atra* with reduced whorls that are not adherent. One carpogonium was observed and a few carposporophytes, which were within the species circumscription of this taxon.

Numerous specimens from Africa in herbaria had manuscript names from H. Skuja that were never published; as such, they have no priority in the ICN (Table 1) (Entwisle 1992). Since the naming suggests that these may be unique, these specimens were examined to determine to which segregate genus from *Batrachospermum* they belonged, and whether any morphological characters could be identified that warranted a new species. Specimens labelled '*Batrachospermum proximum*' and '*B. velatocarpum*' showed morphological characters similar to *Kumanoa nodiflorum* and the new species of *Kumanoa* sp. nov. such that we have assigned those specimens to the new species of *Kumanoa* from Africa based on morphology and geography (Table 2). The specimens labelled '*Batrachospermum jadinii*' and '*B. mucronatum*' had curled carpogonial branches and were designated *Kumanoa* sp. The specimens of '*Batrachospermum stephensii*' and '*B. libericum*' fit the description of *Visia* having carpogonia on long, straight branches, carposporangia not particularly large, and the overall gametophyte morphology. The specimens of '*Sirodotia plumula*' and '*Batrachospermum vanderystii*' were

not examined and have been labelled as *Sirodotia* sp. and *Batrachospermum* sp., respectively. Other specimens examined from herbaria were identified to genus or species when possible, employing morphological characters from recent taxonomic treatments (Table 2).

TAXONOMIC AND NOMENCLATURAL PROPOSALS

Kumanoa bouwmanii* A.L.Szinte, J.C.Taylor & M.L.Vis *sp. nov.

Figs 6-9

DESCRIPTION: Thalli moderately mucilaginous, delicate; approximately 7 cm high; upon drying a light purple colour; branching irregular and abundant. Whorls reduced, distinct and separate, elongate-obconic, 264-320 µm in diameter. Internode 474-557 (655) µm long. Primary fascicles straight, 5-8 cell-storeys. Secondary fascicles covering the entire internode and as long as the primary fascicles. Monoecious. Spermatangia sub-spherical or spherical, terminal or sub-terminal on primary or secondary fascicles, 5-8 µm in diameter. Carpogonial branches compact, twisted arising from the pericentral cells. Involucral filaments short, if present. Carpogonia 24-40(-50) µm long; trichogynes club-shaped, unstalked, 9-12(-15) µm in diameter. Carposporophytes 1-2 per whorl, dense, hemispherical as high as the whorl radius, 255-302 µm in diameter. Gonimoblast filaments 3-4 cell-storeys, cells barrel-shaped; carposporangia sub-spherical 16-28 µm long, 12-24 µm in diameter.

Representative unique molecular sequences deposited in GenBank: *rbc*L MN974516; COI-5P MN974521.

HOLOTYPE: Zambia, Lufubu River at Chipili Village, M13 road-bridge, North-Western Zambia, 10º43'44" S, 29º05'40.38" E, Coll. J.C. Taylor. 01.vi.2012, SANDC 19-564.

ISOTYPE: BHO A-0950.

ETYMOLOGY: The specific epithet is named in honor of Professor H. Bouwman, Professor of Zoology at North-West University who has provided support and encouragement for a variety of projects in the biological sciences, including algal studies.

DISTRIBUTION: Known only from type locality.

REMARKS: This species has molecular data that ally it with *K. montagnei* and *K. nodiflora*. The morphology is distinct from *K. montagnei*, which has well-developed barrel-shaped whorls. The morphology of *K. bouwmanii* and *K. nodiflora* are much more similar with both species having reduced, distinct obconic whorls. It can be distinguished from *K. nodiflora* based on the following characteristics: shorter gonimoblast filaments and somewhat larger carposporangia in both diameter and length. Although there are slight morphological differences, DNA sequence data are recommended for a positive identification.

Sheathia murpheyi A.L.Szinte, J.C.Taylor & M.L.Vis _sp. nov._

Figs 10-12

DESCRIPTION: Thalli delicate; less than 2 cm high; upon drying a light pink colour; branching irregular and abundant. Whorls well-developed, distinct and separate, barrel-shaped, 260-339 µm in diameter. Thick cortication on the main axis composed only of cylindrical cells. Primary fascicles straight, 4-8 cell-storeys. Secondary fascicles few to none. Potentially dioecious, no spermatangia observed. Carpogonial branch straight composed of 4-5 undifferentiated cells that do not differ from the fascicles. Carpogonium 23-32 µm long; trichogyne symmetrical or slightly asymmetrical, fusiform to clavate, 6-9 µm in diameter. Carpogonia present on involucral filaments of carpogonial branch. No carposporophytes observed.

Representative unique molecular sequences deposited in GenBank: *rbc*L MN974517; COI-5P MN974522.

HOLOTOYPE: Zambia, Luwumbu River at M14 road-bridge, Nyika Region, Northern Zambia, 10º44'45.77" S, 33º26'31.63" E , Coll. J.C. Taylor, 02.vii.2011, SANDC 19-565.

ISOTYPE: BHO A-0947

ETYMOLOGY: The specific epithet is named in honor of Dr. K. Murphey retired from Glasgow University who is an aquatic macrophyte specialist and project leader for the Southern African River Assessment Scheme (SAFRASS) project during which the samples from Zambia were collected.

DISTRIBUTION: Known from type locality.

REMARKS: Both *S. murpheyi* and *S. arcuata* are distinguished from other *Sheathia* species based on regular cortication. The most recent species circumscription of *S. arcuata* is quite broad (Vis *et al*. 2010) and *S. murpheyi* is not distinguishable from this taxon without DNA sequence data. In the phylogenetic trees, *S. murpheyi* was sister to a clade of *S. arcuata* specimens that were primarily sporophytes and one gametophyte from Taiwan; this specimen and *S. murpheyi* did differ in carpogonial length (15-20 µm versus 23-32 µm, respectively; Chou & Wang 2006; Vis *et al*. 2010).

Sirodotia kennedyi **A.L.Szinte, J.C.Taylor & M.L.Vis** ***sp. nov.***

Figs 13-16

DESCRIPTION: Thalli delicate; less than 2 cm high; becoming brown on drying; branching irregular. Whorls reduced, obconic to pear-shaped, separate to confluent, 198-315 µm in diameter. Internode 82-90 µm long. Primary fascicles straight, 3-5 cell-storeys. Secondary

fascicles present, but not covering the whole internode. Potentially dioecious, no spermatangia observed. Carpogonial branch composed of 3-4 undifferentiated cells. Carpogonia 25-40 µm long with an asymmetrical base. Trichogynes elongate pyriform or irregularly-shaped, unstalked, 7-11 µm in diameter. Carposporophytes with carposporangia on one-celled branches from an indeterminate prostrate gonimoblast filament. Carposporangia obovoidal, 9-10 µm long, 6-7 µm wide.

Representative unique molecular sequence deposited in GenBank: *rbc*L MN974518.

HOLOTOYPE: Zambia, Mutinondo River, Mutinondo Wilderness, 12º16'06.08" S, 31º22'52.15" E, Coll. M.P. Kennedy, 07.vii.2011, SANDC 19-566.

ISOTYPE: BHO A-0946.

ETYMOLOGY: The specific epithet is named in honor of Dr. M. Kennedy of Coventry University, an aquatic macrophyte specialist/environmental scientist and participant in the Southern African River Assessment Scheme (SAFRASS) project in Zambia and who drove many thousands of kilometers to obtain samples.

DISTRIBUTION: Known only from type locality.

REMARKS: *Sirodotia kennedyi* has similar gametophyte morphology and sizes of carpogonia to *S. delicatula* and *S. suecica*, and shorter carpogonia than *S. huillensis* and *S*. aff. *huillensis*. The other characters used to distinguish *Sirodotia* species, the origin of the gonimoblast filaments and spermatangial placement were not observed in *S. kennedyi* (Lam et al. 2012). Therefore, DNA sequence data is needed to distinguish this species from congeners.

Chantransia azurea* A.L.Szinte, J.C.Taylor & M.L.Vis [form] *sp. nov.

Fig. 17

DESCRIPTION: Thalli consisted of erect filaments twining around other algae and moss. Cells were bright blue. Filaments were highly and irregularly branched, with mostly cylindrical cells, 19-29 µm long, 5-11 µm wide. Apical cells were 6-13 µm long, 3-8 µm wide rarely terminating in a hyaline hair. No monosporangia observed.

Representative unique molecular sequences deposited in GenBank: *rbc*L MN974515; COI-5P MN974520.

HOLOTYPE: South Africa: R321 before Newberg Dam, approximately 10 km from Grabouw near Cape Town, 34º04'46" S, 19º03'29" E, Coll. M.L. Vis, W.B. Chiasson & G. Ellis, 22.viii.2005, BHO A-1434.

ETYMOLOGY: The specific epithet refers to the brilliant blue color of the specimens in the field and after drying.

DISTRIBUTION: Known from type locality.

REMARKS: The thalli completely covered the main axis of a *Batrachospermum*-like gametophyte, but the gametophyte was too immature to identify. This taxon, '*Chantransia azurea*' is quite unique in its DNA sequence and if there had been a gametophyte specimen, it would have been described as a new genus within the order; however, given the lack of morphological data, we have chosen to recognize it as a distinct entity as a form taxon.

Nomenclatural Changes

***Torularia atra* (Hudson) M.J.Wynne**

HETEROTYPIC SYNONYM: *Batrachospermum patens* Suhr 1840: 296, no fig.

REMARKS: *B. patens* is placed in taxonomic synonymy with *Torularia atra* based on an examination of a syntype collection in the Muséum National d'Histoire Naturelle - PC0473547. We hereby designate that collection the lectotype of *Batrachospermum patens* Suhr.

***Montagnia macrospora* (Montagne) Necchi, M.L.Vis & A.S.Garcia**

HETEROTYPIC SYNONYM: *Batrachospermum bohneri* Schmidle 1899: 2

REMARKS: No physical specimens of *Batrachospermum bohneri* have been located in the pertinent herbarium (ZT). However, the description in the protologue by Schmidle (1899a) and the drawings in Schmidle (1899b) of the same material reveal the morphological characteristics, especially the carposporangium size, to be the same as those of *M. macrospora,* demonstrating that these two taxa are conspecific.

Problematic Taxa

***Batrachospermum africanum* Rabenhorst 1855: 281 (as 'afrikanum')**

Specimens examined in this study from PC and FH were not red algae and it could not be determined whether these were type material. Nevertheless, Entwisle (1992) examined isotype material in MEL noting that it was a mixture of two distinct *Batrachospermum* taxa and that it was unclear which was *B. africanum* according to Rabenhorst's description such that this taxon remains uncertain.

***Sirodotia angolensis* (West & G.S.West) Skuja in Reis 1960: 53**

The basionym of this taxon is *Batrachospermum angolensis*. Sheath *et al*. (1993) examined type material of *B. angolensis* and determined it to be a taxonomic synonym of *Torularia*

411 *puiggariana*. These authors may not have been aware of the combination of *S. angolensis*.
412 Therefore, we denote *S. angolensis* as a heterotypic synonym of *Torularia puiggariana*
413 (Grunow) M.J.Wynne 2019: 2.
414
415 **DISCUSSION**
416 **Systematics of taxa from Africa**
417 *Sheathia murphyi* was within a large clade of specimens from locations worldwide that have
418 previously been attributed to *S. arcuata* (Vis *et al*. 2010). However, the sequence variation
419 among *S. arcuata* is much greater than other species of the genus (Salomaki *et al*. 2014). In that
420 study, it was suggested that *S. arcuata* represents a species complex and should be reexamined
421 given the geographic patterns among the subclades. Vis *et al*. (2010) did not observe clear
422 morphological differences among specimens representing the subclades and were reticent to
423 describe new species based on DNA sequence data alone. More recently, species that can only be
424 distinguished via DNA sequence data have become more common in the literature for marine
425 and freshwater red algae (e.g. Diaz-Tapia 2019; Necchi *et al*. 2019a, b). We decided not to add to
426 this species complex but decided to propose a new species based on DNA sequence data and
427 geographic distinctiveness. This species complex will need further investigation as delineating
428 species from this complex is beyond the scope of the current study.
429 *Batrachospermum breutelii* Rabenhorst appears to be endemic to South Africa and has
430 only been reported from two localities worldwide (Sheath & Whittick 1995). This species is
431 distinct with very large zonate carposporangia that resemble fungal spores. There is no doubt that
432 it would have been easily identified if collected at other locations. Due to its unique morphology,
433 *Batrachospermum* section *Gonimopropagulum* was erected. Like many of the sections, it

probably deserves generic status. However, no DNA sequence data exist in order to verify its placement among the genera of Batrachospermales. So, at present it remains a species of *Batrachospermum*, but it does not share the characters of the species of *Batrachospermum* section *Batrachospermum*.

African Flora and Biogeography

With this study, the number of Batrachospermales taxa from Africa with sequence data totals eight: 'Chantransia azurea', *Kumanoa bouwmanii*, *K. iriomotensis*, *Sheathia murpheyi*, *Sirodotia* aff. *huillensis, S. kennedyi, S. suecica* and *Torularia atra.* Although this is a small number of species in the order and probably on the continent, it would appear that the flora has numerous endemic species as five of the taxa had unique DNA sequences. *Sirodotia suecica* and *Torularia atra* are cosmopolitan species with identical or similar sequences from other continents i.e. Australia, Europe and North America and Asia, Australia, Europe (Lam *et al*. 2012; Rossignolo & Necchi 2016). Although *Kumanoa iriomotensis* is known from Asia based on morphology, there is only sequence data from a South Africa specimen, so no conclusion can be drawn based on molecular data as to whether it is more widespread (Necchi & Vis 2012). Even without *K. iriomotensis*, five of eight (*c.* 62%) specimens sequenced were distinctive, suggesting a potentially unique flora. The diatoms also show similar patterns in terms of endemism with certain taxa being regionally endemic and others cosmopolitan (e.g. Taylor *et al*. 2016).

There have been a modest number of literature reports and herbarium specimens collected in Africa. From our assessment of these records, we conclude that *Kumanoa*, *Sirodotia* and *Torularia* have often been collected and are relatively geographically widespread with two or more species present. *Kumanoa* is represented by *K. bouwmanii*, *K. gracillima* (West &

457 G.S.West) Entwisle, M.L.Vis, W.B.Chiasson, Necchi & A.R.Sherwood and *K. iriomotensis*, but
458 there were numerous other specimens that could not be confidently identified to species such that
459 there is a high probability of more species. Likewise, there are three species of *Sirodotia*: *S.*
460 *kennedyi*, *S.* aff. *huillensis* and *S. suecica*, and numerous other specimens that had to be labelled
461 *Sirodotia* sp. Two of the three species in *Torularia* [*T. atra* and *T. puiggariana* (Grunow)
462 M.J.Wynne] are part of the African flora. The genera *Montagnia*, *Nothocladus*, *Paralemanea*,
463 *Sheathia* and *Visia* each are represented by at least one species in the flora. *Batrachospermum*
464 *breutelii* has a distinctive carposporangium such that it can be recognized by morphology alone.
465 Although many reports could be verified using DNA sequencing or morphology, some reports
466 could not be verified, in particular, *Batrachospermum turfosum* Bory from *Batrachospermum*
467 section *Turfosa*. It is probable that a member of this section would be part of the flora given that
468 this section is known to inhabit streams and bogs with acidic brown waters (Sheath *et al*. 1994;
469 Eloranta *et al*. 2011). Two reports of *Tuomeya* and *Batrachospermum gelatinosum* (L.)DC., are
470 dubious. *Tuomeya* is a monospecific genus first described from and widespread in eastern North
471 America (Kaczmarczyk *et al*. 1992). It is unlikely that this species has a disjunct distribution in
472 South Africa. *Batrachospermum gelatinosum* is a northern hemisphere taxon occurring in North
473 America and Europe; other reports from the southern hemisphere were shown to be a cryptic
474 taxon, *Nothocladus pseudogelatinosus* (Entwisle & M.L.Vis) Entwisle & M.L.Vis (Entwisle *et*
475 *al*. 2004, 2016). It is unclear if *Lemanea* may be part of the flora or not based on the report of
476 Montagne (1846). In the present study, we examined a specimen attributed to *Lemanea* and
477 determined it was *Paralemanea*, a sister genus similar in gross morphology. Since, both genera
478 are widespread on other continents, it is equivocal in our opinion as to whether the report is

479 *Lemanea* or *Paralemanea* without a specimen to examine. Excluding the dubious records of
480 taxa, we estimate between 14-19 batrachospermalean taxa in the African flora.

481 The current number of taxa attributable to the African flora is considerably lower than
482 other continents and large countries which have been the focus of freshwater red algal studies.
483 The floras of North America and Europe each have over 40 taxa currently recognized (Eloranta
484 *et al*. 2011, Sheath & Vis 2015, Chapuis *et al*. 2017, Evans *et al*. 2018). Australia, which is more
485 isolated, has over 25 taxa (Vis & Entwisle 2000; Necchi & Vis 2012; Entwisle *et al*. 2018). Over
486 20 species have been recorded from Brazil and Finland (Necchi & Vis 2012, Necchi et al. 2019a,
487 b; Rossignolo & Necchi 2016; Necchi *et al*. 2018; Eloranta 2019). Therefore, it seems likely that
488 with more study, the number of recognized species from Africa will grow and could easily
489 double or triple based on the numbers from these other studies.
490
491 **SUPPLEMENTARY DATA**
492 Supplementary data associated with this article can be found online at http://
493
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500
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662

663 **FIGURE LEGENDS**

664

665 Fig. 1. Map of freshwater red algae reported from Africa with the taxonomy updated as per the
666 results of this study. Symbols with numbers are multiple reports or specimens and symbols with
667 "*" are reports from a country without locality information. More detailed information in Tables
668 1, 2 and Supplementary Table S1.

669 Fig. 2. Maximum likelihood (ML) phylogeny showing relationships of specimens from Africa
670 with all other genera and select species of Batrachospermales based on *rbc*L and COI-5P
671 concatenated sequence data. Support values shown as ML bootstrap / posterior probability from
672 Bayesian inference. Dashes (-) indicate support <80% bootstrap / 0.8 posterior probability.
673 Outgroup taxa of Thoreales (*Thorea hispida, Thorea okadae, Nemalionopsis shawii*) not shown
674 in tree. GenBank accession numbers for included taxa given in Supplementary Tables S1, S2.
675 Scale represents substitutions per site.

676 Fig. 3. Maximum likelihood (ML) phylogeny showing relationships of specimens from Africa
677 with all other species of *Kumanoa* based on *rbc*L sequence data. Support values shown as ML
678 bootstrap / posterior probability from Bayesian inference. Dashes (-) indicate support <80%
679 bootstrap / 0.8 posterior probability. Outgroup taxa and GenBank accession numbers not shown
680 in tree but are included in Supplementary Table S3. Scale represents substitutions per site.

681 Fig. 4. Maximum likelihood (ML) phylogeny showing relationships of specimens from Africa
682 with all other species of *Sheathia* based on *rbc*L sequence data. Support values shown as
683 bootstrap / posterior probability from Bayesian inference. Dashes (-) indicate support <80%
684 bootstrap / 0.8 posterior probability. Outgroup taxa and GenBank accession numbers not shown
685 in final tree but are included in Supplementary Table S4. Scale represents substitutions per site.

686 Fig. 5. Maximum likelihood (ML) phylogeny showing relationships of specimens from Africa
687 with all other species of *Sirodotia* based on *rbc*L sequence data. Labelling of specimens of
688 *Sirodotia* sp. follows Paiano & Necchi 2013. Support values shown as bootstrap / posterior
689 probability from Bayesian inference. Dashes (-) indicate support <80% bootstrap / 0.8 posterior
690 probability. Outgroup taxa and GenBank accession numbers not shown in final tree but are
691 included in Supplementary Table S5. Scale represents substitutions per site.
692 Figs 6-17. Morphology of new species in *Kumanoa*, *Sheathia* and *Sirodotia*.
693 Figs 6-9. Morphology of *Kumanoa bouwmanii sp. nov*.,
694 Fig. 6. Elongate-obconic whorls with large dense carposporophytes (arrows) that are as high as
695 the whorl. Scale = 150 μm.
696 Fig. 7. Fascicles with spermatangia at tips (arrows). Scale = 20 μm.
697 Fig. 8. Carpogonia with club-shaped trichogynes (arrows) on compact, twisted carpogonial
698 branch (arrowhead). Scale = 20 μm.
699 Fig. 9. Carposporophyte with sub-spherical carposporangia (arrows) at the tips of multi-celled
700 gonimoblast filaments. Scale = 20 μm.
701 Figs 10-12. Morphology of *Sheathia murpheyi sp. nov*.
702 Fig. 10. Barrel-shaped whorls (arrow) of main axis with no secondary fascicle evident such that
703 whorls appear well separated. Scale = 150 μm.
704 Fig. 11. Carpogonium with slightly asymmetrical clavate trichogyne (arrow). Scale = 20 μm.
705 Fig. 12. Carpogonium with clavate trichogyne (arrow) on carpogonial branch with
706 undifferentiated cells (arrowhead). Involucral filament of primary carpogonium with secondary
707 carpogonium with fusiform trichogyne (double arrowhead). Scale = 20 μm.
708

709 Figs 13-16. Morphology of *Sirodotia kennedyi sp. nov*.

710 Fig. 13. Reduced obconic whorls (arrow). Scale = 100 μm.

711 Fig. 14. Carpogonium with elongate pyriform trichogyne (arrow) with asymmetrical base

712 (arrowhead) on few-celled carpogonial branch (double arrowhead). Scale = 20 μm.

713 Fig. 15. Carpogonium with irregular trichogyne (arrow) with asymmetrical base (arrowhead) on

714 few-celled carpogonial branch (double arrowhead). Scale = 20 μm.

715 Fig. 16. Carposporophyte with carposporangia (arrows) on one-celled branch from indeterminate

716 prostrate gonimoblast filament (arrowheads). Scale = 20 μm.

717 Fig 17. Habit of *Chantransia azurea* [form] *sp. nov.* with highly branched audouinelloid

718 filaments twining around gametophyte of *Batrachospermum* sp. Scale = 50 μm.

719

720 Supplemental Figures and Tables.

721 Fig. S1. Maximum likelihood (ML) phylogeny showing relationships of specimens from Africa

722 with all other genera and select species of Batrachospermales based on *rbc*L sequence data.

723 Support values shown as ML bootstrap / posterior probability from Bayesian inference. Dashes (-

724) indicate support <80% bootstrap / 0.8 posterior probability. Outgroup taxa of Thoreales

725 (*Thorea hispida, Thorea okadae, Nemalionopsis shawii*) not shown in tree. GenBank accession

726 numbers for included taxa given in Supplementary Tables S1, S2.

727 Fig. S2. Maximum likelihood (ML) phylogeny showing relationships of specimens from Africa

728 with all other genera and select species of Batrachospermales based on COI-5P concatenated

729 sequence data. Support values shown as ML bootstrap / posterior probability from Bayesian

730 inference. Dashes (-) indicate support <80% bootstrap / 0.8 posterior probability. Outgroup taxa

731 of Thoreales (*Thorea hispida, Thorea okadae, Nemalionopsis shawii*) not shown in tree.

732 GenBank accession numbers for included taxa given in Supplementary Tables S1, S2.

Table 1. Freshwater red algae previously reported in the literature and an unpublished manuscript by Pocock dated 1966[a]. Nomenclature updated per AlgaeBase (Guiry & Guiry 2019).

Taxon	Country	Reference
Acrochaetiales		
Audouinella chalybea (as *Chantransia chalybea*)	South Africa	Pocock (1966)
Audouinella hermannii (as *Audouinella violacea*)	Chad	Compère (1975)
Batrachospermales		
Batrachospermum africanum (as *B. afrikanum*)	South Africa	Rabenhorst (1855)
Batrachospermum bohneri	Cameroon	Schmidle (1899)
Batrachospermum breutelii (as *B. dillenii*)	South Africa	Rabenhorst (1855); Pocock (1966); Sheath & Whittick (1995)
Batrachospermum gelatinosum (as *B. moniliforme*)	Madagascar	Fritsch (1914)
Batrachospermum patens	South Africa	Suhr (1840)
Batrachospermum turfosum (as *B. vagum*)	Ivory Coast, Nigeria	Alika & Akoma (2012); Da *et al*. (1999); Ewebiyi *et al*. (2015)
Batrachospermum sp.	Madagascar	Bourrelly (1964); Bixby *et al*. (2009)
'Chantransia' sp.	South Africa	Pocock (1966)
Kumanoa gracillima (as *Batrachospermum gracillimum*)	Angola, South Africa	West & West (1897); Pocock (1966)
Kumanoa iriomotensis	South Africa	Vis *et al*. (2012)
Lemanea fluviatilis	Algeria	Montagne (1846)
Nothocladus afroaustralis	Madagascar	Skuja (1964)

Sirodotia huillensis (as *Batrachospermum huillense*)	Angola, Madagascar, Réunion (France), South Africa	West & West (1897); Fritsch (1914); Pocock (1966); Bourrelly & Couté (1986b)
Sirodotia aff. *huillensis*	South Africa	Lam *et al*. (2012)
Sirodotia suecica	South Africa	Lam *et al*. (2012)
Sirodotia sp.	Madagascar	Bourrelly (1964)
Torularia atra (as *Batrachospermum dillenii)*	South Africa	Pocock (1966)
Torularia puiggariana (as *Batrachospermum angolense, B. nigrescens*)	Angola	West & West (1897)
Tuomeya americana	South Africa	Borge (1928)
Tuomeya sp.	Madagascar	Bourrelly (1964)
Ceramiales		
Bostrychia moritziana	South Africa	Pocock (1966)
Bostrychia scorpioides	South Africa	Pocock (1966)
Caloglossa leprieurii	South Africa, Madagascar, Mauritius	Bourrelly (1964); Bourrelly & Couté (1986b); Pocock (1966)
Caloglossa ogasawaraensis	Madagascar	Bourrelly (1964)
Compsopogonales		
Compsopogon caeruleus	Algeria, Mauritius	Montagne (1846); Bourrelly & Couté (1986b)
Hildenbrandiales		
Hildenbrandia angolensis	Angola	West & West (1897)
Hildenbrandia rivularis	DR Congo	Kumano (2002)[b]
Thoreales		
Thorea violacea	Réunion (France)	Bory (1808); Bourrelly & Couté (1986a)

[a]Unpublished manuscript – Pocock, M. 1966 "Freshwater Algae in Southern Africa."

[b]Reported in Kumano (2002), but no original reference was found.

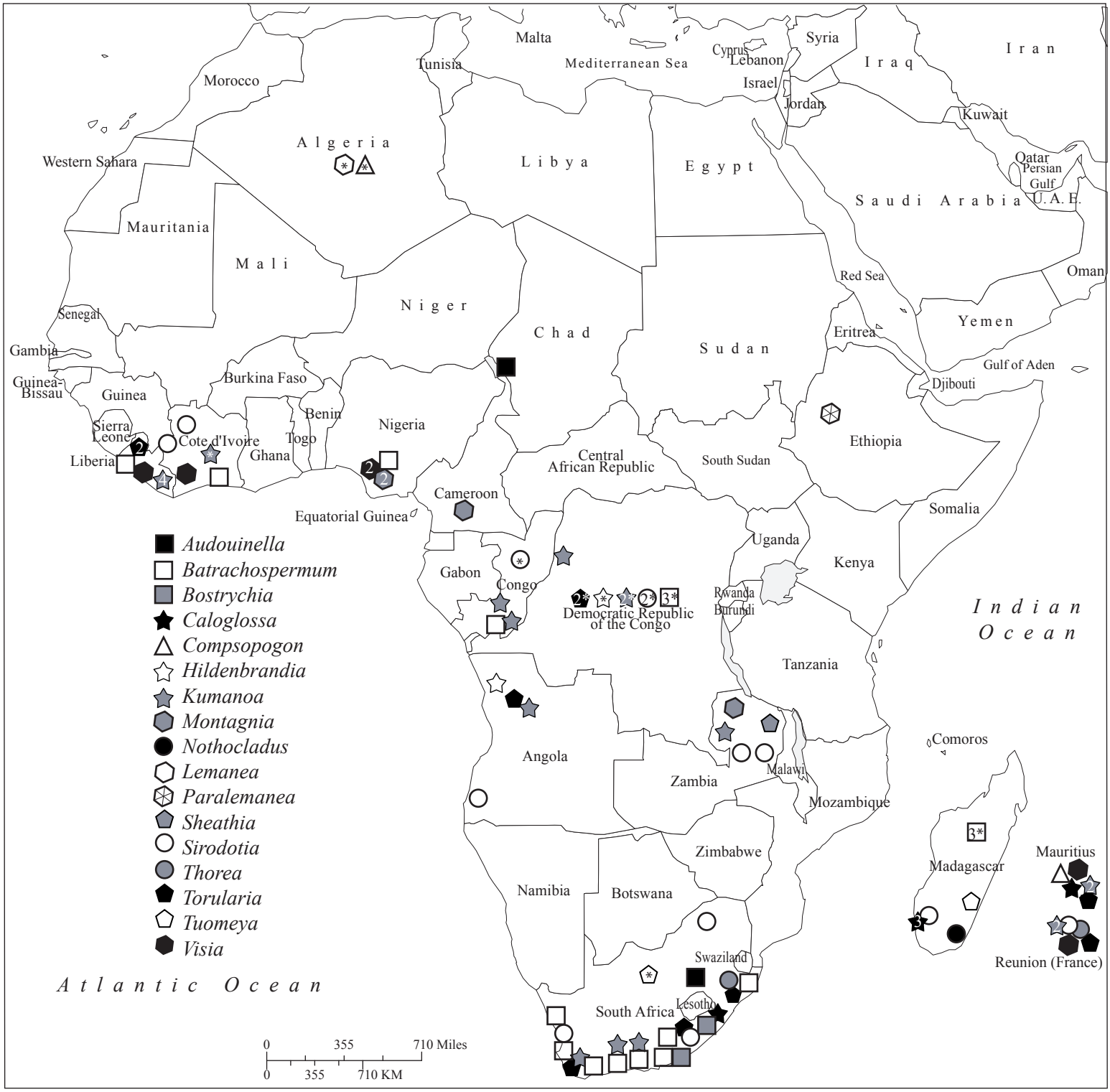
Table 2. Specimens of freshwater red algae of the order Batrachospermales from herbaria. Specimens examined microscopically in italics. If the specimen was not examined, the nomenclature updated per AlgaeBase (Guiry & Guiry 2019).

Name on Specimen label[a]	Identification or nomenclature update	Country	Herbarium specimen(s)[b]
Batrachospermum africanum	chlorophyte	South Africa	BR (1 specimen), *PC0473751-PC0473753, FH00776984*
Batrachospermum breutelii	*Batrachospermum breutelii*	South Africa	PC0658124-PC0658126
Batrachospermum cayennense	*Visia* sp.	Ivory Coast	PC0473719
Batrachospermum dillenii	*Torularia atra*	South Africa	GRA9933
Batrachospermum gracillimum	*Kumanoa gracillima*	DR Congo, South Africa	BR (1 specimen), GRA9934
Batrachospermum guyanense	*Kumanoa* cf. *montagnei*	Liberia	*MICH642679, MICH642680*
Batrachospermum jadini[c]	*Kumanoa* sp.	Mauritius, Reunion (France)	*PC0473640-PC0473652*
Batrachospermum libericum[c]	*Visia* sp.	Liberia	*MICH642707, MICH642708*
Batrachospermum moniliforme	*B. gelatinosum*	Liberia	*FH00778104*[d]
Batrachospermum moniliforme	*Kumanoa* spp.[e]	DR Congo, Liberia	*FH00778102, FH00778103, FH00778105*
Batrachospermum mucronatum[c]	*Kumanoa* sp.	Liberia	*MICH642719, MICH642720*
Batrachospermum patens	*Torularia atra*	South Africa	*PC0473547*
Batrachospermum proximum[c]	*Kumanoa* cf. *bouwmanii*	Liberia	*MICH642925*

Batrachospermum pulchrum	*Batrachospermum pulchrum*	R Congo	PC0473541
Batrachospermum velatocarpum[c]	*Kumanoa* cf. *bouwmanii*	R Congo	*PC0473407*
Batrachospermum radians	*Batrachospermum gelatinosum*	DR Congo	BR (4 specimens)
Batrachospermum stephensii[c]	*Visia* sp.	Mauritius, Reunion (France)	*PC0658087, PC0658088*
Batrachospermum torridum	*Kumanoa* sp.	R Congo, DR Congo, Ivory Coast, Mauritius, Reunion (France)	BR (10 specimens), *PC0473470-0473474*
Batrachospermum vagum	*Batrachospermum turfosum*	South Africa	GRA9936
Batrachospermum vanderystii[c]	*Batrachospermum* sp.	DR Congo	BR (1 specimen)
Batrachospermum sp.	*Batrachospermum* sp.	DR Congo, Madagascar, South Africa	BR (3 specimens), GRA9935, GRA9937
Lemanea sp.	*Paralemanea* sp.	Ethiopia	BR (1 specimen), *MICH661437*
Sirodotia huillensis	*Sirodotia huillensis*	DR Congo, South Africa	BR (3 specimens)
Sirodotia huillensis/ Batrachospermum dillenii	*Sirodotia huillensis*	R Congo[f], Ivory Coast, Madagascar	PC0473382-PC0473390
Sirodotia plumula[c]	*Sirodotia* sp.	DR Congo, Ivory Coast	BR (4 specimens), PC0473381
Sirodotia angolensis	*Torularia puiggariana*	DR Congo, Liberia	BR (2 specimens) *MICH672223*
Sirodotia huillensis	*Torularia puiggariana*	Liberia	*MICH672224*

Sirodotia bambusina[c]	*Torularia or Sirodotia sp.*	Mauritius, Reunion (France)	*PC0473393-PC0473397*

[a]Please note the changes of the names applied to a specific specimen does not denote synonym of names; all nomenclatural changes are in the nomenclatural changes section.
[b]Herbaria abbreviations as follows: BR = Meise Botanic Garden, GRA = Selmar Schonland Herbarium, PC = Muséum National d'Histoire Naturelle, FH = Harvard University, MICH = University of Michigan Herbarium.
[c]Manuscript name or new combination by Skuja, not validly published.
[d]FH00778104 was examined but the material was too degraded to identify whether it is a freshwater red alga; the nomenclature is only updated.
[e]These three specimens represented different collections and although they could not be identified to species, it was clear that FH00778102 was a different species than the other two based on carpogonium length being much longer and the carposporophyte being loose instead of dense.
[f]It is unclear from the herbarium sheet if the record is from R Congo or DR Congo but the sheet stated "Congo."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Algeria
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Libya
Egypt
Qatar
Persian Gulf
Saudi Arabia
U.A.E.
Mauritania
Mali
Niger
Chad
Sudan
Red Sea
Oman
Yemen
Eritrea
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Gulf of Aden
Djibouti
Ethiopia
Sierra Leone
Liberia
Cote d'Ivoire
Ghana
Togo
Central African Republic
South Sudan
Cameroon
Equatorial Guinea
Somalia
Uganda
Kenya
Gabon
Congo
Democratic Republic of the Congo
Rwanda
Burundi
Tanzania
Indian Ocean
Angola
Zambia
Malawi
Mozambique
Comoros
Madagascar
Mauritius
Reunion (France)
Zimbabwe
Namibia
Botswana
Swaziland
Lesotho
South Africa
Audouinella
Batrachospermum
Bostrychia
Caloglossa
Compsopogon
Hildenbrandia
Kumanoa
Montagnia
Nothocladus
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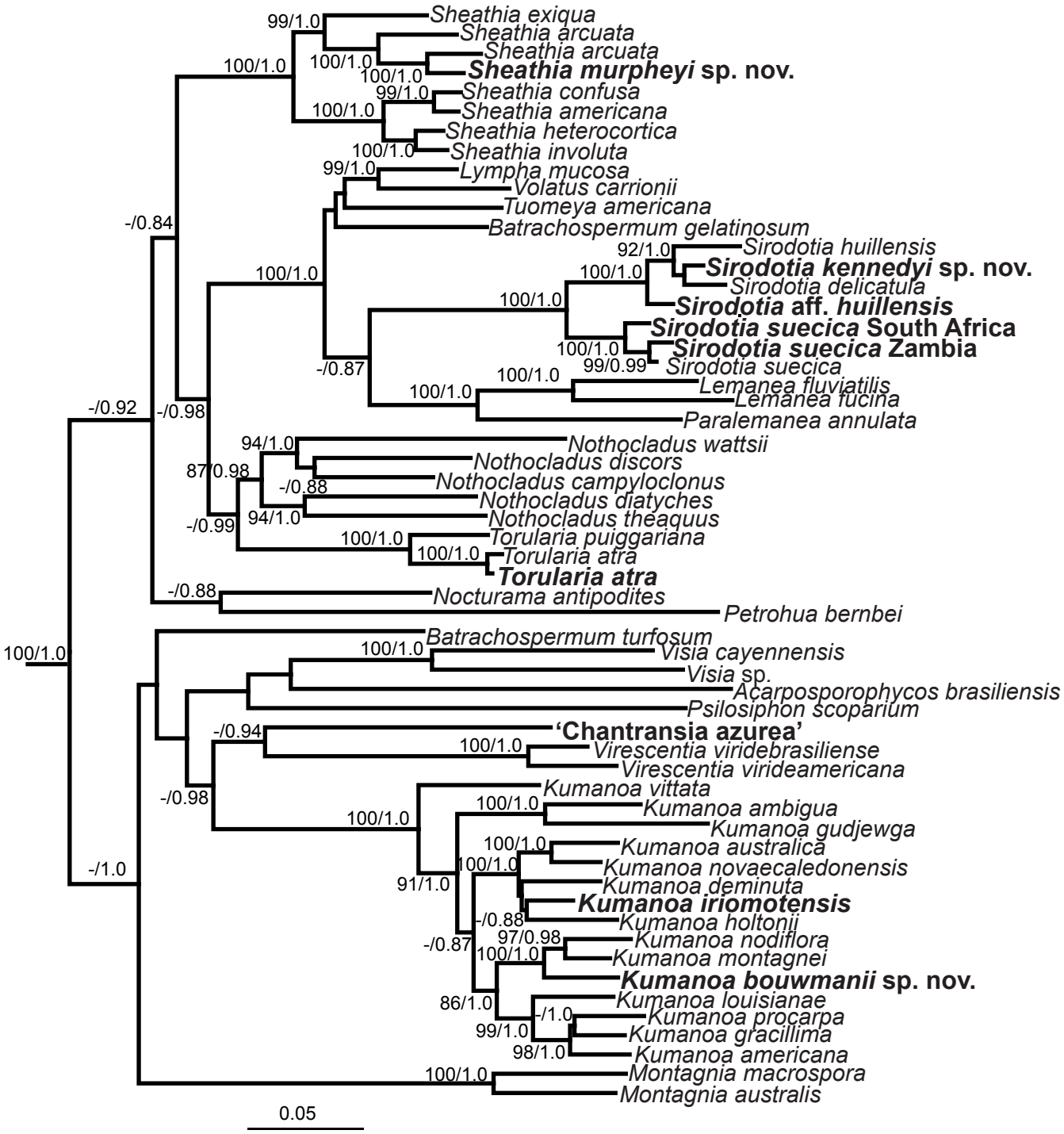
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Lympha mucosa
Volatus carrionii
Tuomeya americana
Batrachospermum gelatinosum
Sirodotia huillensis
Sirodotia kennedyi sp. nov.
Sirodotia delicatula
Sirodotia aff. huillensis
Sirodotia suecica South Africa
Sirodotia suecica Zambia
Sirodotia suecica
Lemanea fluviatilis
Lemanea fucina
Paralemanea annulata
Nothocladus wattsii
Nothocladus discors
Nothocladus campyloclonus
Nothocladus diatyches
Nothocladus theaquus
Torularia puiggariana
Torularia atra
Torularia atra
Nocturama antipodites
Petrohua bernbei
Batrachospermum turfosum
Visia cayennensis
Visia sp.
Acarposporophycos brasiliensis
Psilosiphon scoparium
'Chantransia azurea'
Virescentia viridebrasiliense
Virescentia virideamericana
Kumanoa vittata
Kumanoa ambigua
Kumanoa gudjewga
Kumanoa australica
Kumanoa novaecaledonensis
Kumanoa deminuta
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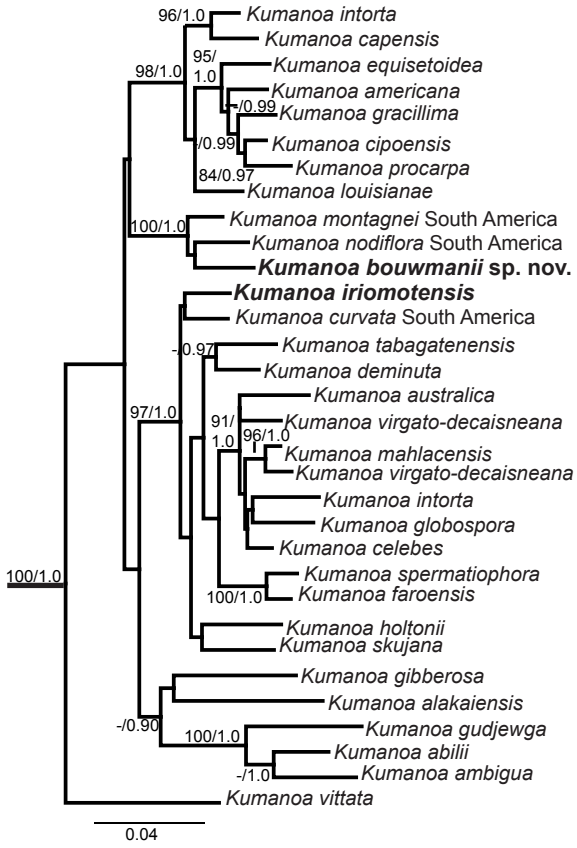
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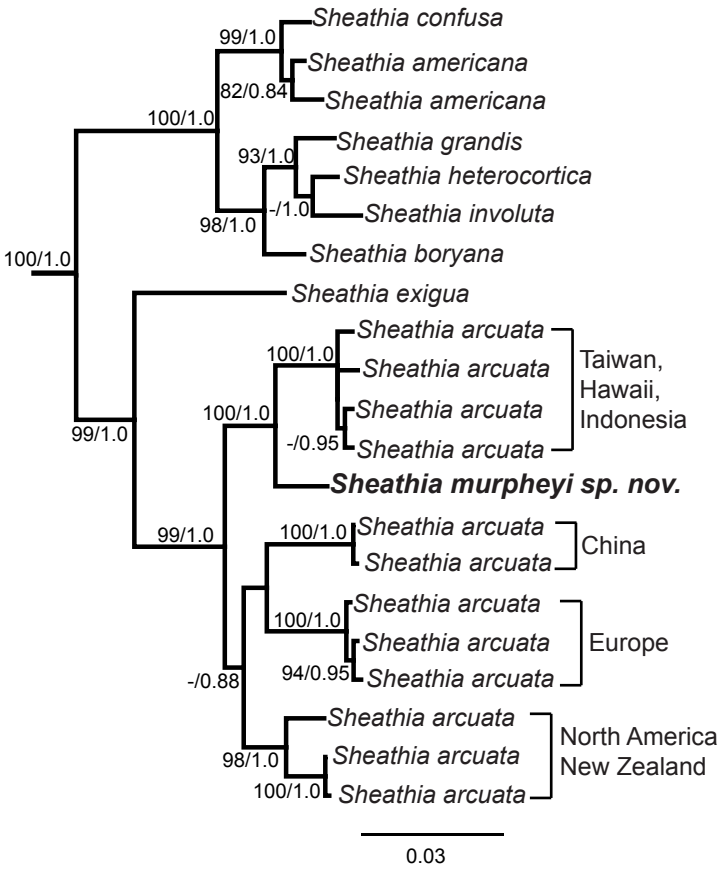
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Taiwan,
Hawaii,
Indonesia
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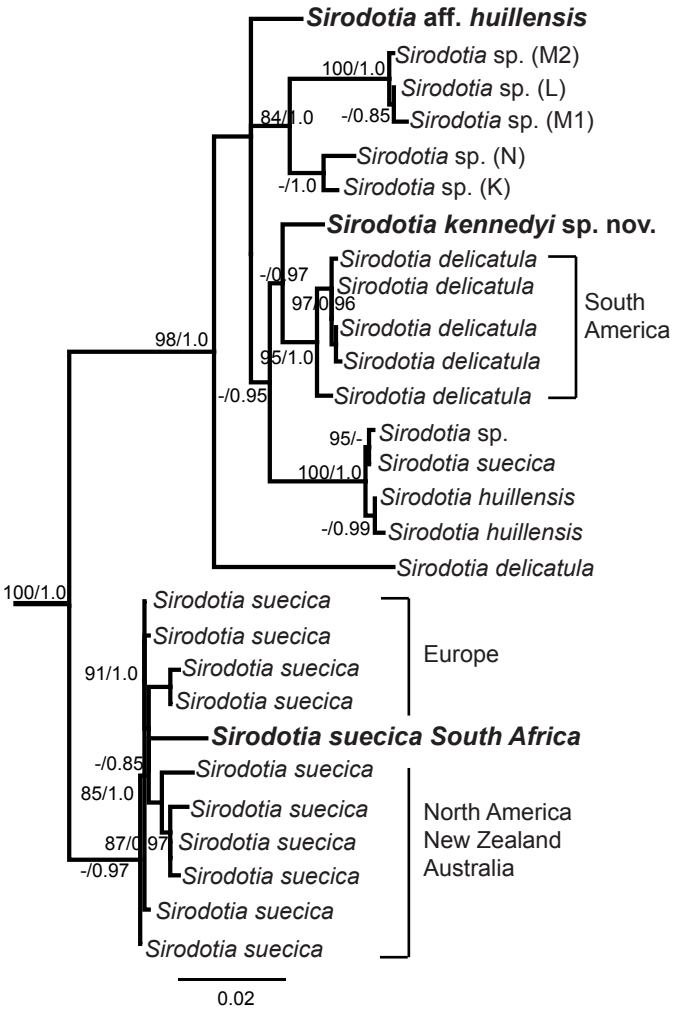
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Sirodotia kennedyi sp. nov.
Sirodotia delicatula
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Sirodotia delicatula
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Sirodotia delicatula
-/0.95
Sirodotia delicatula
South America
98/1.0
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Sirodotia suecica
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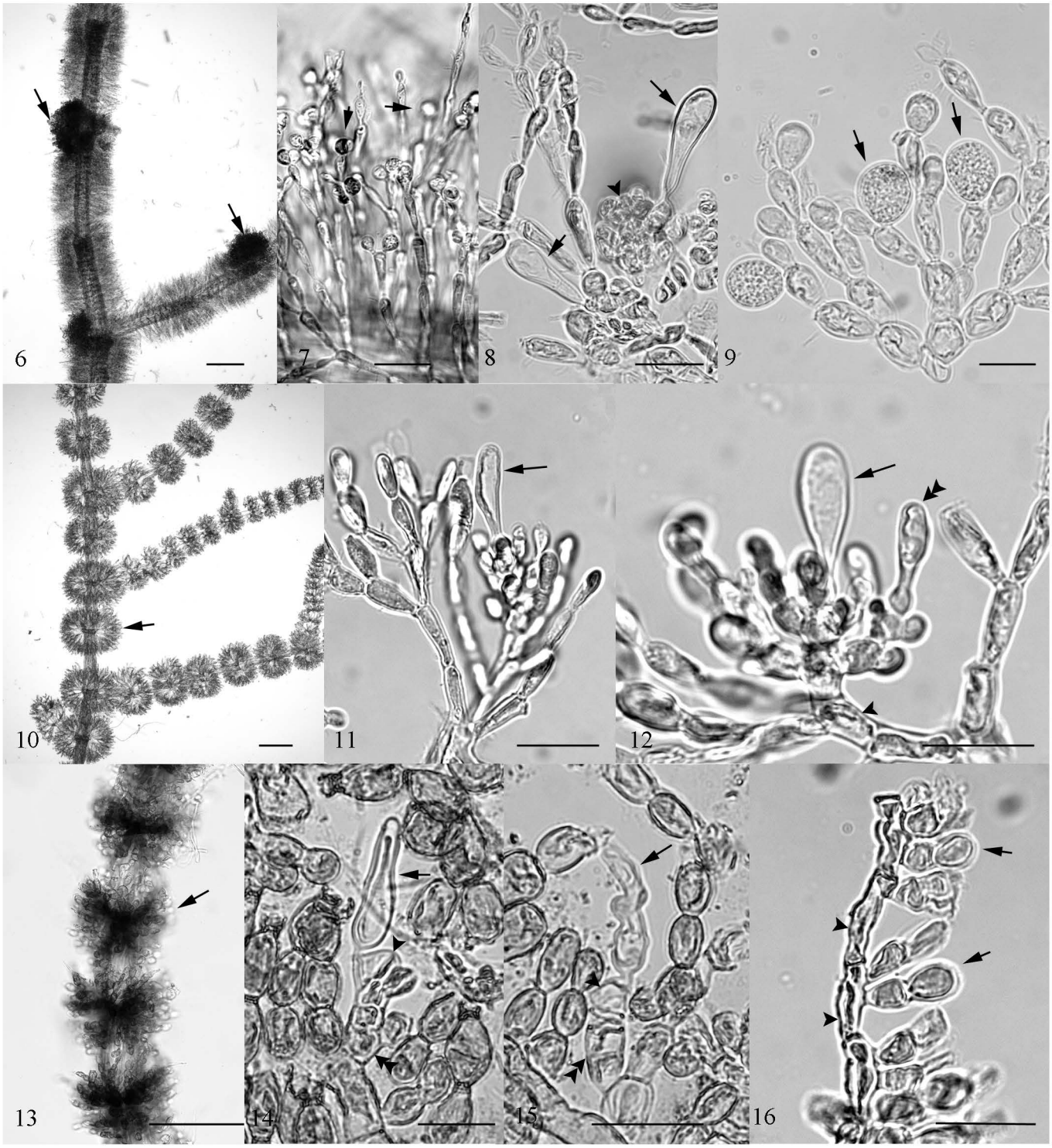
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