Uredinopsis pteridis and *Desmella aneimiae*, the first rust fungi (Pucciniales) reported on ferns (Pteridophyta) in Australia

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Abstract Two species of rust fungi, *Uredinopsis pteridis* on *Pteridium esculentum* and *Desmella aneimiae* on *Nephrolepis hirsutula*, are reported from Australia. These are the first records of rust fungi on species of fern in Australia and the first reports of the genera *Uredinopsis* and *Desmella* in Australia.

Keywords Dennstaedtiaceae · Large Subunit region · Lomariopsidaceae · Pucciniales · Pucciniastraceae · Uredinales

There are an estimated 360 species of rust fungi in Australia (Shivas et al. 2014), none of which occur on ferns (Pteridophyta). Faull (1947) noted that fern rusts had a world-wide distribution, with the exception of Australia. Fern rusts, which belong to genera such as *Hyalopsora*, *Milesina* and *Uredinopsis* (Pucciniastraceae, Pucciniales), often have heteroecious life cycles (Cummins and Hiratsuka 2003). Their aecial stages parasitise species of *Abies* (Pinaceae), which are native to the northern hemisphere (Stevens 2012). *Desmella*, a genus of rust common on ferns in tropical regions, has no known alternate host (Faull 1947).

Specimens of rust on *Pteridium* and *Nephrolepis* from Australia were identified by morphology and molecular

phylogenetic analysis of the 28S region of ribosomal DNA. Rust sori were selectively removed from leaf material with a pipette tip attached to a vacuum pump, and DNA was extracted using the UltraClean Plant DNA Isolation Kit (MoBio Laboratories, Solana Beach, CA, USA). The ITS2-LSU region was amplified with Rust2INV (Aime 2006)/LR7 (Vilgalys and Hester 1990) and nested with LROR/LR6 (Vilgalys and Hester 1990).

A specimen of rust on *Pteridium esculentum* was collected from Port Sorell, Tasmania in Dec. 2013. On the basis of morphology, host and systematic position, we assign this taxon to *Uredinopsis pteridis*.

Uredinopsis pteridis Dietel & Holw., in Dietel, *Ber. dt. bot. Ges.* 13: 331 (1895) (Fig. 1a to c)

Uredinia on lower leaf surface, subepidermal, erumpent, elliptical, up to 1.5 mm, white (Fig. 1a). *Urediniospores* fusiform to subpolyhedrally irregular, apex acute, base sub-acute to truncate, hyaline to subhyaline, 40–64 × 14–21 µm; wall 1–4 µm thick, ridged, 2 longitudinal, marginal ridges of warts along sides, warts 2.5–3 µm (Fig. 1b and c).

Specimen examined: Australia, Tasmania, Port Sorrell, Pitcairn Street (−41.1628, 146.5442), on leaves of *Pteridium esculentum*, 19 Dec. 2013, A.R. McTaggart, L.S. Shuey, M.D.E. & R.G. Shivas, BRIP 60091, 28S GenBank KM249869 Table 1.

Notes — Several species of *Uredinopsis* have been described from *Pteridium* (Berndt 1998; Ziller 1959). These are distinguished from *U. pteridis*, which has urediniospores with a longitudinal band of warts and a generally smooth surface on the remainder of the spore (Berndt 1998; Lopez and Garcia 2002). Berndt (1998) suggested that *U. pteridis* had a cosmopolitan distribution. Our molecular phylogenetic analysis confirmed the placement of BRIP 60091 in *Uredinopsis* (Fig. 2). The aecial stage of *U. pteridis* occurs on species of *Abies* and has not been recorded in Australia.

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Fig. 1 **a to c** *Uredinopsis pteridis* on *Pteridium esculentum* BRIP 60091. (A) Abaxial leaf symptoms; (b, c) Urediniospores. **d to f** *Desmella aneimiae* on *Nephrolepis hirsutula* BRIP 60995. (d) Abaxial leaf symptoms; (e, f) Urediniospores. Scale=10 μm

Table 1 GenBank numbers of taxa included in the phylogenetic analyses

Species	GenBank accession	Reference
<i>Allodus podophylli</i>	JQ423285	Minnis et al. 2012
<i>Blastospora smilacis</i>	DQ354568	Aime 2006
<i>Caeoma torreyae</i>	AF522183	Szaro and Bruns unpublished
<i>Chrysomyxa arctostaphyli</i>	AF522163	Szaro and Bruns unpublished
<i>Coleosporium asterum</i>	DQ354559	Aime 2006
<i>Coleosporium plumeriae</i>	KM249866	This study
<i>Cronartium ribicola</i>	DQ354560	Aime 2006
<i>Desmella aneimiae</i>	KM249867	This study
<i>Endocronartium harknessii</i>	AY700193	Szaro and Bruns unpublished
<i>Halopsora polypodii</i>	AF426229	Maier et al. 2003
<i>Helicobasidium purpureum</i>	AY885168	Matheny and Hibbet unpublished
<i>Hemileia vastatrix</i>	DQ354566	Aime 2006
<i>Milesina philippinensis</i>	KM249868	This study
<i>Naohidemycus vaccinii</i>	DQ354563	Aime 2006
<i>Prospodium tuberculatum</i>	KJ396195	Pegg et al. 2013
<i>Puccinia gnaphalicola</i>	KF690703	McTaggart et al. 2014
<i>Puccinia graminis</i>	AF522177	Bruns et al. 1992
<i>Puccinia lagenophorae</i>	KF690700	McTaggart et al. 2014
<i>Puccinia psidii</i>	KF318447	Pegg et al. 2013
<i>Pucciniastrum circaeae</i>	AY745697	Matheny and Hibbet unpublished
<i>Pucciniastrum epilobii</i>	AF522178	Szaro and Bruns unpublished
<i>Pucciniastrum goeppertianum</i>	AF522180	Szaro and Bruns unpublished
<i>Sphaerophragmium</i> sp.	KJ862350	McTaggart et al. unpublished
<i>Thekopsora minima</i>	KC763340	McTaggart et al. 2013
<i>Uredinopsis filicina</i>	AF426237	Maier et al. 2003
<i>Uredinopsis pteridis</i>	KM249869	This study
<i>Uredinopsis</i> sp.	AF522181	Szaro and Bruns unpublished
<i>Uromyces appendiculatus</i>	KM249870	This study

Fig. 2 Phylogram recovered from a maximum likelihood search and SPR tree improvement in PhyML with an alignment of the LSU region. aRLT values (≥90 %) / and bootstrap values (≥70 %) from a ML search in RAXML with 1,000 bootstrap replicates shown above nodes. Posterior probability values (≥0.95) from a Bayesian analysis in MrBayes

summarized from 3,600 converged trees shown below the nodes. The two taxa reported in this study are in bold font. Pucciniastraceae was recovered as a polyphyletic group, with *Hyalopsora polypodii* sister to Coleosporiaceae and Pucciniastraceae

Specimens of rust on species of *Nephrolepis* and *Goniophlebium percutum* collected from northern Queensland were morphologically identified as *Desmella aneimiae*.

Desmella aneimiae Syd. & P. Syd., *Annls mycol.* 16(3/6): 241 (1919) (Fig. 1d to f)

Uredinia on lower leaf surface, suprastomatal, erumpent, round, white or yellow (Fig. 1d). *Urediniospores* globose, hyaline with yellow cellular contents when fresh, 25–28×24–27 μm; wall uniform, 1.5–2.0 μm thick, echinulate, germ pores absent or inconspicuous (Fig. 1e and f).

Specimens examined: Australia, Queensland, Mossman Rainforest Trail, on *Nephrolepis oblitterata*, 14 Aug. 2006, R. Berndt, V. Faust-Berndt, BRIP 50771; Daintree, Discovery Centre, on *Goniophlebium percussum*, 15 Aug. 2006, R. Berndt, V. Faust-Berndt, BRIP 50770; Kuranda, McDonald's track, on *Nephrolepis* sp., 18 Aug. 2006, R. Berndt, V. Faust-Berndt, BRIP 50772; Kuranda, on *Nephrolepis* sp., Feb 2009, R.G. Shivas, B.C. McNeil, Y.P. Tan, BRIP 52438; Mossman, on *Nephrolepis* sp., 15 Dec. 2009, R.G. Shivas, BRIP 53067; Babinda, on *Nephrolepis hirsutula*, 22 May 2010, A.R. McTaggart, R.G. Shivas, BRIP 53369; Babinda (−17.3413, 145.8694), on *Nephrolepis hirsutula*, 05 Apr. 2014, A.R. McTaggart, S.G. McKenna, BRIP 60995, ITS2-28S GenBank KM249867.

Notes — Uredinia and telia are the only life cycle stages known for *Desmella* (Cummins and Hiratsuka 2003), and Faull (1947) considered it systematically distinct from other species of rust on ferns. The phylogenetic analysis in this study determined *Desmella* to be sister to *Puccinia* and *Uromyces*, and more closely related to Pucciniaceae than to other rusts in the Pucciniaceae on ferns (Fig. 2). The taxonomic sampling in this analysis was not representative of all rust families, and the systematic position of *Desmella* was not determined. Cummins and Hiratsuka (2003) treated *Desmella* in the Uropyxidaceae.

Fern rusts were considered ancestral to all other species of Pucciniales under the hypothesis that parasites were closely linked to the evolution of their hosts (Leppik 1953). Hart (1988) used a morphological cladistic approach to show fern rusts adapted to pre-existing hosts, and had a close relationship to other rust fungi on Pinaceae. This result was supported by a molecular phylogenetic study on the 18S region of rDNA by Sjamsuridzal et al. (1999), who also determined rust fungi on ferns were non-monophyletic. The systematic position of *Desmella* recovered in this study further supports the hypothesis made by Hart (1988) that the evolution of some rust fungi was sequential, with an adaptation to a pre-existing host followed by extensive radiation through co-speciation or host shifting.

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