Biodiversity of Australian smut fungi

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There are about 250 species of smut fungi known from Australia of which 95 are endemic. Fourteen of these endemic species were first collected in the period culminating with the publication of Daniel McAlpine's revision of Australian smut fungi in 1910. Of the 68 species treated by McAlpine, 10 were considered to be endemic to Australia at that time. Only 23 of the species treated by McAlpine have names that are currently accepted. During the following eighty years until 1990, a further 31 endemic species were collected and just 11 of these were named and described in that period. Since 1990, 50 further species of endemic smut fungi have been collected and named in Australia. There are 115 species that are restricted to either Australia or to Australia and the neighbouring countries of Indonesia, New Zealand, Papua New Guinea and the Philippines. These 115 endemic species occur in 24 genera, namely *Anthracoidea* (1 species), *Bauerago* (1), *Cintractia* (3), *Dermatosorus* (1), *Entyloma* (3), *Farysporium* (1), *Fulvisporium* (1), *Heterotolyposporium* (1), *Lundquistia* (1), *Macalpinomyces* (4), *Microbotryum* (2), *Moreaua* (20), *Pseudotracya* (1), *Restiosporium* (5), *Sporisorium* (26), *Thecaphora* (2), *Tilletia* (12), *Tolyposporella* (1), *Tranzscheliella* (1), *Urocystis* (2), *Ustanciosporium* (1), *Ustilago* (22), *Websdanea* (1) and *Yelsemia* (2). About a half of these local and regional endemic species occur on grasses and a quarter on sedges. The northern tropical savannah region of Australia offers most promise for the discovery of new endemic species. The agricultural, quarantine and environmental significance to Australia of some introduced species is discussed.

Key Words: biodiversity, smut fungi, Ustilaginomycetes

Introduction

In 1802 the eminent British botanist Robert Brown, while collecting specimens of a sedge near Port Jackson (now Sydney), unknowingly made the first collection of an Australian smut fungus (Ustilaginomycetes) that was parasitising the seeds (Walker, 1971). Brown's specimens provided the lectotype of *Cyperus lucidus*, and the smut fungus, discovered amongst herbarium specimens of the sedge more than 150 years later, is now known as

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Bauerago cyperi-lucidi (J. Walker) K. Vánky. A little more than a century after this accidental beginning, the first and only taxonomic revision of Australian smut fungi, *The Smuts of Australia*, appeared by McAlpine (1910) who treated 68 species. Now, 200 years ago since Robert Brown's collection, about 250 species of smut fungus have been discovered in Australia and the number of endemic species has risen to 95. In this paper we briefly explore the biodiversity of Australian smut fungi in the context of endemism, host specificity, phytogeography as well as agricultural, quarantine and environmental significance.

Endemism

It is convenient to divide the two centuries that have elapsed since the first smut was collected in Australia in 1802, into three periods. The first period from 1802 until 1910 represents the time of greatest botanical and geographical discovery in Australia. This was a period that started with British colonisation and exploration; was followed by the introduction of broad acre farming systems, particularly for cereals and livestock; and eventually saw the birth of the Australian nation in 1901. During this period the first endemic species of smut fungus in Australia was published by Nees (1846) on a native Western Australian rush (*Restionaceae*) under the name of *Uredo restionum* Nees (Websdane *et al*., 1994).

Daniel McAlpine (1849-1932) made his founding and most influential contributions to taxonomic mycology and plant pathology in Australia (May and Pascoe, 1996). This era culminated with McAlpine's revision of Australian smut fungi in 1910. His treatment documented all that was known about the Australian smut fungi at that time and it is still the only comprehensive treatment on the subject today. McAlpine (1910) treated 68 species of which 26 were new species of smut. Of these 68 species only 23 have names that are accepted today. Ten of the 68 species known to McAlpine were considered to be endemic to Australia although this number increased to 17 if species restricted to Australia and New Zealand were included (Table 2). With hindsight we now know that in 1910 there were a further five species of Australian endemic smut fungi that lay in collections awaiting critical examination (Table 1). Unfortunately the period up to 1910 also saw the introduction into Australia of ten of the most serious exotic smut diseases of cereals (Table 5).

The next period, from 1910 until 1990, sees Australia's population rapidly colonise the eastern coastal regions and massive land clearing for broad acre farms expand into the heart of the continent. During this period, 31 species

Table 1. Chronological list (according to year first collected) of species of smut fungi known to occur only in Australia together with year basionym published.

Year first collected in Australia	Australian species	Year basionym published
up to 1910:		
1802	*Bauerago cyperi-lucidi* (J. Walker) K. Vánky	1971
1839	*Restiosporium restionum* (Nees) K. Vánky	1846
1850	*Restiosporium leptocarpi* (Berk.) K. Vánky	1881
1878	*Moreaua muelleriana* (Thümen) K. Vánky	1878
1889	*Ustilago tepperi* Ludwig	1889
1890	*Ustilago pertusa* Tracy & Earle	1895
1891	*Ustilago distichlidis* (McAlpine) Ciferri	1928
1894	*Thecaphora lagenophorae* (McAlpine) McAlpine	1910
1897	*Moreaua gigaglomerulosa* K. Vánky	2002
1902	*Urocystis destruens* McAlpine	1910
?1903	*Sporisorium mitchellii* (Syd. & P. Syd.) K. Vánky	1903
1903	*Restiosporium lepidobolii* (McAlpine) K. Vánky	1904
1904	*Moreaua lepidospermae* (McAlpine) K. Vánky	1910
1909	*Sporisorium walkeri* K. Vánky	1994
1910-1990:		
1910	*Macalpinomyces ewartii* (McAlpine) K. Vánky & R.G. Shivas	1911
1911	*Ustilago panici-gracilis* MacKinnon	1912
1911	*Sporisorium exsertiformum* K. Vánky	1995
1923	*Urocystis chorizandrae* J. Cunnington, R.G. Shivas & K. Vánky	in press
1931	*Ustilago curta* Syd.	1937
1931	*Sporisorium polycarpum* (Syd.) K. Vánky	1937
1932	*Sporisorium fraserianum* (Syd.) K. Vánky	1937
1933	*Sporisorium centrale* R.G. Shivas & K. Vánky	2002
1935	*Ustilago altilis* Syd.	1937
1935	*Ustilago radulans* K. Vánky	1999
1936	*Ustilago serena* Syd.	1937
1938	*Ustilago lepturi-xerophili* K. Vánky	1999
1940	*Tilletia palpera* J. Walker	2001
1941	*Sporisorium eulaliae* (L. Ling) K. Vánky	1953
1947	*Ustilago porosa* Langdon	1962
1947	*Microbotryum prostratum* (K. Vánky & Oberw.) K. Vánky	1991
1951	*Fulvisporium restifaciens* (D.E. Shaw) K. Vánky	1952
1953	*Entyloma arctotis* K. Vánky	2000
1961	*Microbotryum dumosum* (K. Vánky & Oberw.) K. Vánky	1990
1963	*Moreaua opaca* K. Vánky	2002
1964	*Tilletia nigrifaciens* Langdon & Boughton	1978
1968	*Thecaphora maireanum* R.G. Shivas & K. Vánky	in press
1971	*Lundquistia fascicularis* K. Vánky	2001
1974	*Moreaua elongata* K. Vánky	2002

Table 1 (continued).

Year first collected in Australia	Australian species	Year basionym published
1974	*Pseudotracya otteliae* K. Vánky	1999
1976	*Ustilago latzii* K. Vánky	2001
1978	*Ustilago alcornii* K. Vánky	2000
1982	*Ustilago enteropogonis* K. Vánky	2002
1984	*Sporisorium simile* R.G. Shivas & J. Walker	1998
1989	*Tilletia pseudochaetochloae* R.G. Shivas & K. Vánky	2002
1989	*Ustilago neurachnis* K. Vánky	2002
1990-2002:		
1990	*Yelsemia arthropodii* J. Walker	2001
1991	*Sporisorium cenchri-elymoidis* K. Vánky & R.G. Shivas	2002
1992	*Moreaua cyathochaetae* (Websdane & K. Vánky) K. Vánky	1996
1992	*Moreaua mesomelaenae* (Websdane & K. Vánky) K. Vánky	1996
1992	*Tilletia robeana* K. Vánky	2002
1992	*Websdanea lyginiae* (Websdane, Sivasithamparam, Dixon & Pate) K. Vánky	1993
1992	*Moreaua tricostulariae* (Websdane & K. Vánky) K. Vánky	1996
1993	*Moreaua evandrae* (Websdane & K. Vánky) K. Vánky	1996
1993	*Moreaua laevigata* (Websdane & K. Vánky) K. Vánky	1995
1993	*Moreaua melanospora* (Websdane & K. Vánky) K. Vánky	1996
1994	*Moreaua caustidis* (K. Vánky) K. Vánky	1996
1995	*Tilletia lineata* R.G. Shivas & K. Vánky	2001
1995	*Sporisorium ordense* R.G. Shivas & K. Vánky	1997
1995	*Sporisorium paraneurachnis* R.G. Shivas & K. Vánky	1997
1996	*Entyloma bracteanthae* K. Vánky	1997
1996	*Heterotolyposporium lepidospermae* K. Vánky	1997
1996	*Moreaua gahniae* (K. & C. Vánky) K. Vánky	1997
1996	*Moreaua gymnoschoeni* (K. & C. Vánky) K. Vánky	1997
1996	*Moreaua megaglomerulosa* (K. Vánky) K. Vánky	1997
1996	*Moreaua tetrariae* (K. Vánky) K. Vánky	1997
1996	*Restiosporium meneyae* K. Vánky	2000
1996	*Ustilago triodiae* K. Vánky	1997
1996	*Ustilago xerochloae* K. Vánky & R.G. Shivas	1997
1996	*Ustilago inaltilis* K. Vánky & A.A. Mitchell	1998
1997	*Sporisorium iseilematis-ciliati* K. Vánky	1998
1998	*Cintractia bulbostylidis* R.G. Shivas & K. Vánky	2001
1998	*Sporisorium iseilematis-vaginiflori* K. Vánky	1999
1998	*Sporisorium whiteochloae* K. Vánky & McKenzie	2001
1998	*Sporisorium ryleyi* K. Vánky & R.G. Shivas	2001
1999	*Sporisorium normanensis* R.G. Shivas & K. Vánky	2002
1999	*Tilletia kimberleyensis* K. Vánky & R.G. Shivas	2001
2000	*Cinctractia lipocarphae* K. & C. Vánky & R.G. Shivas	2001
2000	*Macalpinomyces brachiariae* K. & C. Vánky & R.G. Shivas	in press
2000	*Macalpinomyces digitariae* K. Vánky & R.G. Shivas	in press

Table 1 (continued).

Year first collected in Australia	Australian species	Year basionym published
2000	*Moreaua arthrostylidis* K. Vánky & R.G. Shivas	2001
2000	*Moreaua fimbristylidis* K. Vánky & R.G. Shivas	2001
2000	*Sporisorium gibbosum* K. & C. Vánky & R.G. Shivas	2001
2000	*Sporisorium horsfallii* K. Vánky	2001
2000	*Sporisorium nervosum* K. & C. Vánky & R.G. Shivas	2001
2000	*Sporisorium operculatum* K. & C. Vánky & R.G. Shivas	2001
2000	*Sporisorium queenslandicum* K. & C. Vánky & R.G. Shivas	2001
2000	*Tilletia cape-yorkensis* K. Vánky & R.G. Shivas	in press
2000	*Tilletia chionachnes* K. & C. Vánky & R.G. Shivas	2001
2000	*Tilletia whiteochloae* R.G. Shivas & K. Vánky	2001
2000	*Ustilago chloridis* K. & C. Vánky & R.G. Shivas	2001
2001	*Dermatosorus schoenoplecti* K. Vánky & R.G. Shivas	in press
2001	*Entyloma grampiansis* K. Vánky & R.G. Shivas	in press
2001	*Restiosporium baloskionis* K. Vánky & R.G. Shivas	in press
2001	*Ustanciosporium tenellum* R.G. Shivas & K. Vánky	in press
2002	*Yelsemia lowrieana* R.G. Shivas & K. Vánky	in press

of endemic smut fungi were first collected in Australia (Table 1). However only 11 of these species were named and described during that period, which calculates on average at less than one new species every seven years.

The third period, from 1990 to the present, coincides with a belated community realisation of the potential economic and social importance of biodiversity and habitat preservation. It is also the period that sees the development of modern taxonomic methods that utilise the tools of ultrastructural and molecular analysis. A product of these new methods is the development of a new classification system for the smut fungi (Bauer *et al*., 1997; Begerow *et al*., 1997; Vánky, 2001), which surprisingly shows some smut fungi (*Microbotryales*) are more closely related to rust fungi (*Uredinales*) than to other smuts.

During this period of only twelve years, a further 50 species of endemic smut fungi were first collected and named in Australia (e.g. Shivas and Vánky, 2001; Vánky and Shivas, 2001, Table 1). This period marks a rapid increase in the rate that new endemic species of smut fungi are discovered, from a steady rate of about one species every three years in the previous hundred years to about four species per year since 1990 (Fig. 1). This recent period coincides with a time that the Australian community has sought to sustain its agricultural systems and preserve its natural environment through surveillance programs, primarily for the early detection of incursions of exotic pathogens. This mostly

Table 2. Chronological list (according to year first collected in Australia) of species of smut fungi known to occur only in Australia and neighbouring countries together with year basionym published.

Year first collected in Australia	Australian species	Year basionym published
	Also occurring in New Zealand:	
1845	*Cinctractia solida* (Berk.) M. Piepenbr.	1860
1891	*Moreaua rodwayi* (McAlpine) K. Vánky	1910
1892	*Ustilago agropyri* McAlpine	1896
1892	*Tranzscheliella comburens* (Ludwig) K. Vánky & E. McKenzie	1893
1892	*Ustilago spinificis* Ludwig	1893
1894	*Tilletia inolens* McAlpine	1896
1895	*Ustilago bullata* Berk.	1855
1898	*Moreaua schoeni* (K. Vánky & E. McKenzie) K. Vánky	1995
1940	*Tilletia cathcartae* Durán & G.W. Fischer	1961
1947	*Arthracoidea sclerotiformis* (Cooke & Massee) Kukkonen	1888
1979	*Farysporium endotrichum* (Berk.) K. Vánky	1855
	Also occurring in Indonesia and/or Papua New Guinea and/or Philippines:	
1855	*Macalpinomyces eriachnis* (Thümen) Langdon & Fullerton	1878
1892	*Ustilago confusa* Massee	1892
1941	*Sporisorium langdonii* K. Vánky	1994
1970	*Sporisorium themedae-arrguentis* K. Vánky	1994
1995	*Tilletia opaca* Syd. & P. Syd.	1913
1996	*Sporisorium australasiaticum* K. Vánky & R.G. Shivas	2001
1996	*Sporisorium chamaeraphis* (Syd.) K. Vánky	1928
1999	*Sporisorium anthracoideisporum* K. Vánky & R.G. Shivas	1998
2000	*Tolyposporella pachycarpa* (Syd.) L. Ling	1928

government-funded surveillance has focused on northern Australia because of its proximity to potential pathways for exotic pathogens through Indonesia and Papua New Guinea. Many new smut fungi have been found during botanical and plant pathological surveys in northern Australia organised as part of this surveillance.

Host specificity

About half of the endemic species of smut fungi in Australia occur on grasses (*Poaceae*) and about a quarter on sedges (*Cyperaceae*) (Table 4), which reflects the host specificity of Ustilaginomycetes worldwide (Vánky, 2002). Of the species of smut fungi parasitising grasses in Australia, about two-thirds have panicoid (*Panicoideae*) hosts. A pattern of host specificity was

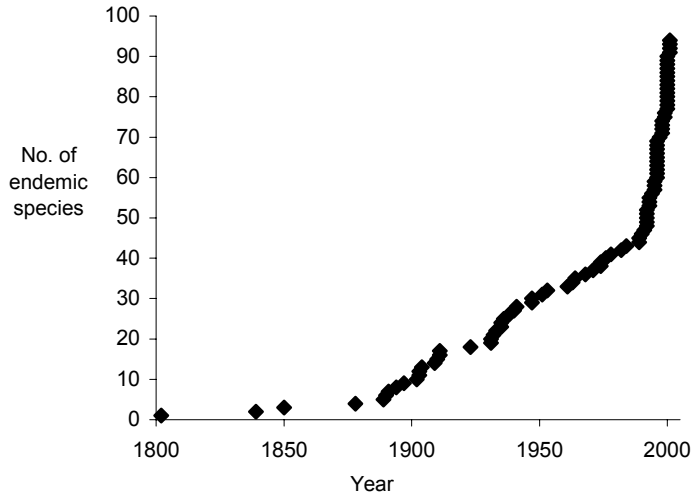

Fig. 1. Chart of the accumulated number of endemic species of smut fungi known in Australia since the first collection in 1802.

also seen for some genera of smut fungi amongst the subfamilies of grasses. Almost exclusively, species of *Sporisorium* had panicoid hosts and species of *Ustilago* were mostly restricted to the two subfamilies (*Chloridoideae* and *Panicoideae*). McAlpine (1910) was aware of four species (all in *Ustilago*) of endemic smut fungi on grasses, yet eleven new endemic species of smut fungi were collected on grasses in Australia in the year 2000 alone (Table 1). As there are about 150 genera (containing more than 1,000 species) of grasses native to Australia (Simon, 1993) it is certain that many more species of smut fungi on native grasses remain to be discovered.

About three-quarters of the endemic smut fungi that parasitise sedges in Australia belong to the genus *Moreaua* (Table 4). More than half of these endemic species of *Moreaua* were first collected in the last decade (Table 1). In Australia there are about 650 species of sedge in 47 genera (Wilson, 1988), and it is very likely that many more species of *Moreaua* await discovery.

Other than the grasses and sedges, there is no taxonomic group of plants in Australia that host more than 5% of the endemic species of smut fungi. There are about 150 species of rushes (*Restionales*) in Australia (Meney and Pate, 1999), yet this large and diverse group hosts only six endemic species of smut fungi (Table 4) in two endemic genera, *Restiosporium* and *Websdanea*.

Table 3. Genera and number of species of 115 endemic smut fungi (those listed in Tables 1 and 2) in the major Australian phytogeographic regions (modified from Doing, 1981).

Genera of endemic smut fungi (no. of species)	Phytogeographic region (climate)				
	Central Australian desert, mulga and mallee scrubland (arid)	**Eastern forest (tropical to cool temperate with an absence of arid periods)**	**Northern savannah (tropical with summer rains)**	**South-eastern savannah (sub-tropical to temperate)**	**South-western forest and heath (Mediterranean to semi-arid)**
Arthracoidea (1)	-	1	-	-	-
Bauerago (1)	-	1	-	1	-
Cinctractia (3)	1	1	1	1	-
Dermatosorus (1)	-	1	-	-	-
Entyloma (3)	-	3	-	-	-
Farysporium (1)	-	1	-	-	-
Fulvisporium (1)	-	-	-	1	-
Heterotolyposporium (1)	-	-	-	1	-
Lundquistia (1)	-	-	-	1	-
Macalpinomyces (4)	1	1	4	1	-
Microbotryum (2)	-	1	-	1	-
Moreaua (20)	1	10	1	4	8

Table 3. (continued).

Genera of endemic smut fungi (no. of species)	Phytogeographic region (climate)				
	Central Australian desert, mulga and mallee scrubland (arid)	**Eastern forest (tropical to cool temperate with an absence of arid periods)**	**Northern savannah (tropical with summer rains)**	**South-eastern savannah (sub-tropical to temperate)**	**South-western forest and heath (Mediterranean to semi-arid)**
Pseudotracya (1)	-	-	-	1	-
Restiosporium (5)	-	3	-	-	2
Sporisorium (26)	5	4	15	6	-
Thecaphora (2)	1	1	-	-	-
Tilletia (12)	-	4	7	1	-
Tolyposporella (1)	-	-	1	-	-
Tranzscheliella (1)	1	1	-	1	1
Urocystis (2)	-	2	-	-	-
Ustanciosporium (1)	1	-	-	-	-
Ustilago (22)	9	7	8	6	2
Websdanea (1)	-	-	-	-	1
Yelsemia (2)	1	-	1	-	-
Total number of species	**21**	**42**	**38**	**26**	**14**

Table 4. Higher order classification of host plants (according to Cronquist, 1988; Wilson, 1988; Simon, 1993) of endemic species of Australian smut fungi (those listed in Tables 1 and 2).

Host classification	Smut genus (no. of endemic species)
Magnoliopsida *(dicotyledons)*	
Caryophyllidae	
Caryophyllales	*Thecaphora* (1)
Polygonales	*Microbotryum* (2)
Rosidae	
Apiales (Hydrocotylaceae)	*Entyloma* (1)
Rosales (Byblidaceae)	*Yelsemia* (1)
Asteridae	
Asterales	*Entyloma* (2), *Thecaphora* (1)
Liliopsida (monocotyledons)	
Alismatidae	
Hydrocharitales	*Pseudotracya* (1)
Commelinidae	
Restionales	*Restiosporium* (5), *Websdanea* (1)
Cyperales	
Cyperaceae	
Caricoideae	*Arthracoidea* (1)
Cyperoideae	*Bauerago* (1), *Cinctractia* (3), *Dermatosorus* (1), *Farysporium* (1), *Heterotolyposporium* (1), *Moreaua* (20), *Urocystis* (1), *Ustanciosporium* (1)
Poaceae	
Arundinoideae	*Macalpinomyces* (1), *Sporisorium* (1), *Tilletia* (2), *Tranzscheliella* (1), *Ustilago* (1)
Stipoideae	*Fulvisporium* (1)
Pooideae	*Tilletia* (3), *Ustilago* (1)
Chloridoideae	*Sporisorium* (1), *Ustilago* (12)
Panicoideae	
Panicodae	*Lundquistia* (1), *Macalpinomyces* (2), *Sporisorium* (8), *Tilletia* (5), *Ustilago* (7)
Andropogonodae	*Macalpinomyces* (1), *Sporisorium* (16), *Tilletia* (2), *Tolyposporella* (1), *Ustilago* (1)
Liliidae	
Liliales	*Urocystis* (1), *Yelsemia* (1)

Table 5. Chronological list (according to year first collected in Australia) of species of smut fungi of agricultural, quarantine or environmental significance.

Year first collected	Species	Significance
1877	*Urocystis tritici* Körn.	Flag smut of wheat was first described from a specimen collected in South Australia.
1890	*Ustilago nuda* (J.L. Jensen) Kellerm. & Swingle	Loose smut of barley.
1892	*Ustilago tritici* (Westend.) Niessl	Loose smut of barley and wheat.
1892	*Ustilago avenae* (Pers.) Rostr.	Loose smut of oats.
1895	*Sporisorium sorghi* Ehren. ex Link	Covered smut of cultivated sorghum.
1896	*Urocystis agropyri* (Preuss) A.A. Fisch. Waldh.	Flag smut of wheat.
1899	*Tilletia laevis* Kühn	Stinking smut or bunt of wheat.
1903	*Tilletia caries* (DC.) Tul.	Stinking smut or bunt of wheat.
1903	*Ustilago hordei* (Pers.) Lagerh.	Covered smut of barley.
1907	*Urocystis occulta* (Wallr.) Rabenh. ex Fuckel	Flag smut of rye.
1908	*Tilletia contraversa* Kühn in Rabenh.	In Australia this smut is known only on wild barley grass (Langdon *et al*., 1976). In other parts of the world it causes dwarf bunt of winter wheat, barley, rye and other grasses.
1915	*Ustilago maydis* (DC.) Corda	Boil smut of maize was eradicated from Australia in 1940 and then reappeared in New South Wales in 1982 (Allen and Jones, 1983). Quarantine regulations have managed to restrict the spread of boil smut of maize to Western Australia and some districts in other States.
1950	*Urocystis magica* Pass.	Quarantine regulations have ensured that onion smut (also known as *Urocystis cepulae* Frost) has been restricted to infrequent, local outbreaks in South Australia and New South Wales. It was last detected in Australia in 1985 (Walker, 2001).
1967	*Tilletia walkeri* L.A. Castlebury & L.M. Carris	Seed smut of perennial rye grass in Australia and annual ryegrass in USA (Castlebury and Carris, 1999).
1986	*Microbotryum violaceum* (Pers.:Pers.) G. Deml & Oberw.	Anther smut of carnation was found at a few plant nurseries in southern Queensland. The smut was traced back to imported elite nursery stock. It was successfully eradicated and has not been seen since 1987.

Table 5. (continued).

Year first collected	Species	Significance
1994	*Sporisorium ophiuri* (Henn.) K. Vánky	Under investigation as a possible biocontrol agent for itch grass (*Rottboellia cochinchinensis*) in Central America (Smith *et al*., 1997).
1998	*Ustilago scitaminea* Syd.	Quarantine regulations have restricted sugarcane smut to the Ord River Irrigation Area in the semi-arid tropics of Western Australia since it was first detected in 1998. It has not been found in the main sugarcane growing regions of eastern Australia

The two centres of diversity of the rushes are South Africa and Australia, in particular southwestern Australia. Interestingly smut fungi have never been recorded on rushes in South Africa.

In Australia only eight of the 115 endemic species of smut fungi have dicotyledonous hosts (Table 4). The eight species have hosts across five orders.

Phytogeography

It is conventional to list the distribution of Australia's flora amongst the States and Territories. However the State boundaries are artificial divides and give little useful indication of the distribution of plant species or habitats. The phytogeographic regions of Australia (Doing, 1981) are more useful measures of determining where hosts, and their pathogens, occur. The distribution of the Australian endemic smut fungi amongst the five major phytogeographic regions (Fig. 2, simplified from Doing, 1981) offers some insights (Table 3).

The eastern forest region that comprises a complexity of plant communities recorded most endemic species of smut fungi (42). However several of the smut species recorded in this region were found on grasses that also occurred in the savannah regions to the west. That most endemic species were found in the eastern forest region compared to the other regions is likely a reflection that most collecting has taken place in this region, which incorporates most of Australia's population centres.

The comparatively large number (15) of endemic species of *Sporisorium* in the northern savannah region (Table 3) correlates with it having mostly panicoid and andropogonoid grass hosts that are primarily tropical species. As it is known that there are several small genera of exclusively tropical smut, not

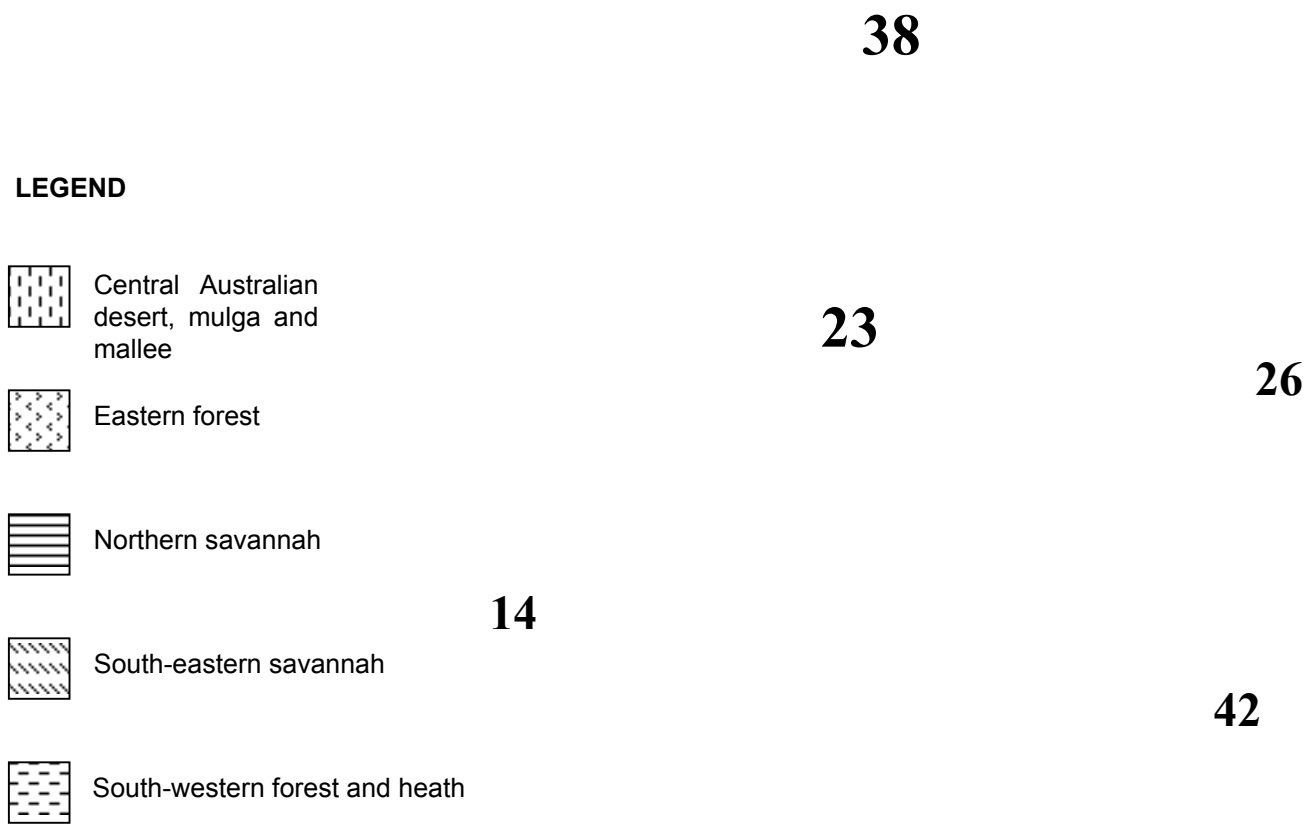

Fig. 2. Five major phytogeographic regions of Australia (simplified from Doing, 1981). Number of species of smut fungi endemic to Australia found in each region is superimposed on map.

all of which are represented in Australia, this region offers most promise for discovering new endemic species of smut fungi.

Perhaps it seems incongruous that endemic smut fungi poorly represent the southwestern forest and heath region, which is rich in endemic plant species. However grasses are not a dominant part of heath and forest communities. The low number of endemic smut species in the arid Central Australian may reflect that this region is floristically poor (Doing, 1981) or that there has been relatively little collecting in the region. Grasses tend to be annual species in this region, which provides a very narrow window of opportunity to collect specimens.

Agricultural, quarantine and environmental significance

By 1915, almost all of the important cereal pathogens had been introduced into Australia (Table 5). Many of these cereal smuts were responsible for devastating losses in the late nineteenth and early twentieth centuries (McAlpine, 1910). Their importance to Australian agriculture has reduced markedly since the introduction of effective fungicidal seed treatments and the development of disease resistant varieties through plant breeding. There are still important exotic smut pathogens of cereals that are not present in Australia, including for example, *Tilletia indica* (karnal bunt of wheat) and *Sporisorium cruentum* (loose smut of sorghum). Their existence underlines the need for vigilant and appropriate quarantine measures (Vánky and McKenzie, 2002) that were so missing in the nineteenth century.

The importance of rigorous quarantine to an isolated island continent is demonstrated by the appearance but failure to establish of three smut fungi that are virtually cosmopolitan outside of Australia. Onion smut, anther smut of carnation and sugarcane smut have all been detected in Australia (Table 5) but each has been severely restricted in distribution, with one, anther smut of carnation, apparently eradicated.

Many of the Australian endemic smut fungi are represented by single, or very few, specimens. These species must be considered rare although it is likely many are not. Undoubtedly there are rare hosts of smut fungi, possibly some threatened with extinction. Habitat destruction in Australia, as evidenced by the massive land clearing that taken place since European colonisation, has certainly accounted for the extinction of many plant species. We have no idea how many endemic smut fungi may also have become extinct with their hosts.

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