How many species of fungi are there at the tip of Africa?

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Abstract: Several recent studies have reviewed the extent of fungal biodiversity, and have used these data as basis for revised estimates of species numbers based on known numbers of plants and insects. None of these studies, however, have focused on fungal biodiversity in South Africa. Coinciding with the 100th anniversary of the National Collection of Fungi (PREM) in South Africa in 2005, it is thus timely to reflect on the taxonomic research that has been conducted in South Africa over the past Century. Information is presented on the extent of fungal collections preserved at PREM, and the associated research publications that have largely resulted from this resource. These data are placed in context of the known plant and insect biodiversity, and used as basis to estimate the potential number of fungi that could be expected in South Africa. The conservative estimate is of approximately 200 000 species without taking into account those associated with a substantial insect biodiversity.

Key words: Biodiversity, conservation, National Collection of Fungi, numbers of fungi, undescribed species.

INTRODUCTION

Defining the number of fungi on earth has always been a point of discussion (Fries 1825, Bisby & Ainsworth 1943), but has gained prominence in scientific literature towards the latter part of the twentieth century. While this exercise might on the surface appear to be of peripheral importance, it is fundamental to understanding and protecting the world’s biodiversity. Thus, a number of studies have in recent years focused on enumerating the world’s fungal biodiversity (Pirozynski 1972, Pascoe 1990, Hawksworth 1991, Dreyfuss & Chapela 1994, Rossman 1994, Hyde 1996, Hyde et al. 1997, Hawksworth 1998, Fröhlich & Hyde 1999, Hawksworth 2001, 2004). They have provided the foundation for studies aimed at a better understanding of fungal biodiversity worldwide, and results have been used to motivate for bioconservation and fungal biodiversity studies.

It is widely recognised that fungi have been relatively poorly collected and studied from most countries, regions and habitats. This is at least in comparison to plants and larger animals that are considerably easier to collect and identify than fungi. One might then have expected that the predicted numbers of fungi on earth would have been considerably greater than the 1.5 M suggested by Hawksworth (1991). Clearly different authors that have considered the likely total number of fungi have had differing views of an appropriate answer, but the discrepancy between the results of most of these studies is not particularly great. It is currently accepted that the 1.5 M estimate is highly conservative. The 100 000 that have thus far been described, therefore represents no more than 7 % of the estimated total.

One hundred years of mycology in South Africa as celebrated in this volume is not a particularly long history for mycology as science. The country is widely recognised as one of the world’s biodiversity “hotspots”, including areas such as the Cape Floral Kingdom, which is the smallest and most diverse biome presently known. This paper aims to summarize the major mycological developments that have happened in South Africa, as well as to provide an estimate of the number of fungi in this country. In a paper such as this it is never possible to comment on all activities and groups that have been active over the past 100 years, and for many of these there will only be a brief mention, chiefly because much of the information was not available to us at the time this paper was written. Nevertheless, it is hoped that this summary and estimate will not only be interesting, but also provide a foundation to promote and guide future mycological activity in South Africa and elsewhere.

UNIQUE SOUTHERN AFRICAN FLORA

Germishuizen & Meyer (2003) list just over 24 500 taxa (including those at infraspecific level) as occurring in the flora of the southern African region, which includes South Africa, Botswana, Lesotho, Swaziland and Namibia. They observe that this means that about 10 % of the world’s flora occurs in less than 2.5 % of the total land area of the world. This represents an increase of about 500 taxa on the previous checklist of this flora (Arnold & de Wet 1993). By no means is all of this increase due to “cryptic” taxa appearing as a result of new revisions, or new invader plants appearing in our...
area. Plant collectors are finding previously unknown taxa in ever more inaccessible areas, sometimes embarrassingly close to major centres of population. As examples of these discoveries, one may cite recent papers by Edwards et al. (2005) detailing a new Drimia from within the Durban municipal boundaries, and any one of Van Jaarsveld’s numerous recent discoveries (e.g. Van Jaarsveld et al. 2005; this issue of Aloe contains two other similar new discoveries) from further afield. As an example of a recent invader, one may point to Campylolobium macrocephalum, which became noticeable a few years ago in Pretoria, and has already spread to Durban (mapped and described without historical data by Henderson 2001). In the South African National Biodiversity Institute (SANBI), much systematic research is directed to cataloging plant diversity by means of regional floras; some (Goldblatt & Manning 2000, Retief & Herman 1997) already published and others still in various stages of preparation. Monographic studies tend to be the province of university departments. That both kinds of study are needed is shown by the fact that some groups, notably some genera of legumes, have not been critically examined since the pioneering work of W.H. Harvey, over a century ago (in Harvey & Sonder 1862).

Naturally, these plants are not evenly distributed over southern Africa, and there have been various studies of the vegetation of southern Africa from the historically classic studies of Drège (1843) and Bolus (1886), through Acocks (1953 and still the most often-cited work in South African botany) to the recent studies of Low & Rebelo (1996) and Rutherford & Mucina (in prep.). For the purposes of this contribution, the concepts of biomes and centres of diversity given by Van Wyk & Smith (2001) will be used (Figs 1–2).

Kaokoveld Centre
In the far north-west of Namibia and adjacent southern Angola, the vegetation of this centre is mainly bushveld and semi-desert of the Namib and the arid savannas to the immediate east of it. One of the most striking features of the semi-desert is the so-called fairy rings: circular patches completely devoid of plant cover, surrounded by grass. These are not permanent, and several theories have been put forward to explain their existence. One suggests fungal action (Eicker et al. 1982), but no convincing fungi have been found in them. The presently most-popular theory involves both termites and a biological factor inhibiting the resistance of grasses to desiccation (Albrecht et al. 2001). This area is very poorly known, and the estimate of the flora of 400 species (Viljoen 1980) is likely to be far too low.

Succulent Karoo
This is the arid area to the north and west of the Cape fynbos. Different workers have varying concepts of the boundaries of the area, giving rise to varying estimates of the number of species present. A current SANBI project to prepare a flora of the area is working on some 4 000 species (Paterson-Jones, pers. comm.), but other estimates with wider geographical limits put the plant diversity as high as 5 000 species. Many of the plants here are succulents, but another significant part of the flora is made up of ephemeral annuals. In both groups, it is known that not all seeds from a given year will germinate together; up to half the crop will remain dormant until at least the second rainy season after they have ripened.

Cape Floristic Region
The fynbos of the Western Cape has been studied for longer than any other part of sub-Saharan Africa, and so should be among the best-known floras in Africa. However, it is also among the world’s most diverse. A recent synopsis of the flora of this region (Goldblatt & Manning 2000) lists some 9000 species for this area, approximately 80 % of which are endemic. Sadly much of the area has been replaced by, or is under threat from agriculture and urbanisation. Presently less than 5 % of the West Coast Renosterveld is in pristine condition. The flora here is remarkable for reaching its greatest diversity on essentially nutrient-free soils.

Griqualand West Centre
This region occupies the dry area bounded roughly by a line connecting the towns of Prieska, Vryburg, Vorstershoop and Upington in the Northern Cape Province. The vegetation is mainly various kinds of bushveld, grassland and Karoo. There are many succulents endemic here, but the flora is not as well-known as one may suppose. The only checklist of the plants of the area is by Wilman (1946). Acocks (1953) recorded over 300 species from a single sampling point in the Asbestos Hills – the highest number from any of the thousands of points he sampled for this work.

Albany Centre
This area of endemism stretches westwards from the Kei River roughly to Middleburg, Aberdeen and the Bavianskloof Mountains in the Eastern Cape. The climate is transitional between the summer-rainfall regime of the eastern part of southern Africa and the winter-rainfall climate of the Western Cape, and at first glance the vegetation seems transitional, too. The vegetation is highly varied, with as many as a third (21 of 70) of Acocks’s (1953) veld types and five of White’s (1983) main phytochoria being represented here. A flora of the Eastern Cape is in preparation, and is expected to treat some 8400 species (Bredenkamp, pers. comm.).

Drakensberg Alpine Centre
The highest mountain area in southern Africa includes most of Lesotho, a very mountainous area around Barkly East in the Eastern Cape, and a fringing area stretching along the eastern (seaward) slope of the Drakensberg from there through KwaZulu-Natal to the mountainous area southwest of Harrismith in the Free State. Although this area does not have an up-to-date flora, it is well supplied with comparatively recent field guides (Hilliard & Burt 1987, Killick 1990, Pooley 2003). The last-cited guide, estimates the flora of this centre as comprising some 2200 species, 20 % of which are endemic. Van Rooy (2000) considers this to be one of the
Soutpansberg Centre
The mountains separating the Limpopo Valley from the rest of South Africa have long been known in botanical folklore as interesting, but have only recently been defined as a centre of endemism, running from the Blouberg in the west, along the Soutpansberg and including parts of the Limpopo valley into the north-western corner of the Kruger National Park and a tiny area of Zimbabwe.

Fig. 1. Unique South African flora. A–C. Cape Floristic Region. D. Beach vegetation. E. Coastal forest. F. Mangrove vegetation. G. Ceres Karoo. H–J. Succulent Karoo. K. Bushveld and grassland. L. Wolkberg centre. All photographs by H. Glen, except A by P.W. Crous.
The area contains representatives of 41% of all plant genera and 68% of all plant families in the Flora of southern Africa area (South Africa, Botswana, Lesotho, Swaziland, Namibia), and is certainly a meeting place between the floras of east and west south-tropical Africa (Hahn 1998). The only recent account of the flora of this area specifically is Hahn’s (1994) tree checklist, but the number of plant taxa here is estimated at about 3000.

**Wolkberg Centre**

Stretching from near Carolina, Mpumalanga, in the south to Haenertsburg, Limpopo Province in the north, with a westward extension to Zebediela south of Polokwane, this centre comprises the escarpment areas once known as the Transvaal Drakensberg. The flora numbers between 1500 and 2000 species, some 10% of which are endemic.

**Sekhukhuneland Centre**

Inland of the Wolkberg Centre escarpment is a much drier area, underlain by basic and ultramafic rocks of the Bushveld Igneous Complex; as with the Barberton centre below, this geology may lead one to expect many endemic species. The flora of the area is severely undercollected, but is believed to number some 2000 species (Retief et al. 2001). The importance of the area as a centre of endemism was demonstrated by Siebert (1998), who has also done a still-unpublished phytosociological study of this Centre (Siebert 2001). The vegetation is conventionally considered to be Mixed Bushveld (e.g. Low & Rebelo 1996), but grassland and forest remnants are also to be found there. The flora of the Sekhukhuneland bushveld is unique. However, most of the area has been severely degraded by creeping urbanization and subsistence farming.

**Barberton Centre**

The mountains between Barberton, Mpumalanga Province, and the Swaziland border (stretching into a small part of north-western Swaziland) have a remarkable flora with many endemics. These mountains are geologically complex, and include some of the oldest fossil-bearing rocks on earth (MacRae 1999), as well as serpentinite (noted wherever it occurs for supporting unusual endemic species) and ancient volcanic rocks. Balkwill & Balkwill (1999) report 30 endemic species here, many of them as yet undescribed. However, the rugged terrain means that much of the area is effectively unexplored, and so many other taxa of limited occurrence are no doubt still awaiting discovery (Hurter & Van Wyk 2004).

**Maputaland-Pondoland Region**

This includes almost the whole of the KwaZulu-Natal Province, and a smaller or larger fringe in surrounding areas, most notably southern Mozambique and Eastern Cape (former Transkei). A newly-started project to generate an electronic Flora of KwaZulu-Natal is working on a checklist of some 6500 taxa, suggesting a flora for the whole area of about 7500 species. Vegetationally, the area may be divided into numerous grassland, thicket and forest types. Among the earliest specimens from KwaZulu-Natal are a series collected by Gerrard & McKen in 1860, but serious study of the flora of the

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Fig. 2. Unique South African flora (continued). A. Wolkberg centre. B. Montane grassland. C. Degraded bushveld. D–F. Soutpansberg centre. Photographs by H. Glen.
area may be said to have started with Medley Wood, who founded the first herbarium in the then colony in 1882 (Schrire 1983), and also collected and wrote on some fungi, mostly associated with plant diseases. With the immense variety of plants and habitats in this area, it is hardly surprising that undescribed fungi are found here even more frequently than undescribed plants.

BEGINNING OF MYCOLOGY IN SOUTHERN AFRICA

Mycology in southern Africa was formally initiated by the appointment of I.B. Pole Evans in 1905. At that time, the only fungal collections in the country were those of MacOwan and Medley Wood, consisting of some 765 specimens (Pole Evans 1916). Pole Evans established a national collection of fungi in Pretoria. At the time of publication of Doidge’s book (Doidge 1950), this collection included more than 35 000 fungal specimens. Other fungal collections were housed at Stellenbosch (collections of P.A. van der Bijl and L. Verwoerd), Cape Town (P. MacOwan collection and Bolus herbarium), and at several European herbaria, the most important of which are Kew and the International Mycological Institute (CABI Bioscience). Pole Evans also sent numerous collections to Europe, many to P. Hennings, P. Magnus and H. and P. Sydow. Several collections of larger fungi were also sent to C.G. Lloyd in the U.S.A., and many duplicates can be found in Vienna. Doidge (1950) summarised the content of her book in tabular form, listing (species) 93 Myxomycetes, 77 Phycomycetes, 835 Ascomycetes, 1159 lichens, 1704 Basidiomycetes, 880 fungi imperfecti, making a grand total of 4748 species. Many of these specimens were collected under extremely difficult circumstances and personal danger, which is reported on in detail by Doidge (1950).

Most mycological activity in the post-Doidge era focused on reports of fungi causing plant diseases, with some attention to saprobic fungi, and those found to be mycotoxigenic. Reference works such as the Gorter bulletins (1977, 1979, 1981, 1982), Van der Westhuizen & Eicker (1994), and Eicker & Baxter (1999) provide lists of various groups of fungi compiled after Doidge et al. (1953). Information on fungi subsequent to 1999 can be obtained via the Internet-based electronic system of CAB abstracts (CAB) (www.cabi-publishing.org). Several lists of plant diseases caused by fungi, bacteria and viruses in South Africa have been published. The first of these was Doidge (1924) followed by Doidge & Bottomley (1931) and Doidge et al. (1953), which was chiefly based on Doidge (1950). These records were updated in a series of bulletins published by Gorter.

Fig. 3. Approximate number of species described from South Africa¹.

¹Data derived from Index Fungorum <www.indexfungorum.org/Names/Names.asp>.
²The increase in species during 1980–1999 can chiefly be attributed to the description of a large number of new lichens.
(1977, 1979, 1981, 1982). Later, Crous et al. (2000b) published the compilation “Phytopathogenic Fungi of South Africa”, which was made available online by the Systematic Botany & Mycology Laboratory in the U.S.A., and is searchable via <http://nt.ars-grin.gov/fungal databases/southafrica/>.

INTENSIVELY STUDIED GROUPS

Ascomycetes

The ascomycetes represent a group of fungi that have been relatively widely studied in South Africa. This group of fungi was intensively collected during the Doidge era (Doidge 1950). Subsequently, the emphasis changed (Baxter 1994) from broader-based data collection or taxonomic work and the description of new species to the study of fungi that are important as plant pathogens. This was closely linked to the fact that the responsibility for the National Collection of Fungi was placed with the Plant Protection Research Institute of the National Department of Agriculture. Examples include studies on the Xylariaceae (Martin 1970), Botryosphaeria Ces. & De Not. (Denman et al. 2000, 2003, Slippers et al. 2004a–d), Mycosphaerella Johanson (Crous 1998, Crous et al. 2000a, 2001, 2004c), powdery mildews (Erysipheaceae) (Gorter 1988a, b, 1989), Valsaceae (Adams et al. 2005) and Sclerotinia Fuckel (Thompson & Van der Westhuizen 1979, Phillips 1987, Van der Westhuizen & Eicker 1988), causing diseases on various crop plants. Numerous miscellaneous pathogenic species were newly described, such as Uncinula praeterita Marasas & I.H. Schum. (Marasas & Schumann 1966), a powdery mildew from the indigenous shrub Ehretia rigida, and Magnaporthe rhizophilia D.B. Scott & Deacon (Anelich 1986) from roots of wheat. The teleomorph of Pithomyces chartarum (Berk. & M.A. Curtis) M.B. Ellis, studied for years as a contributing factor in the aetiopathology of “geeldikkop” and facial eczema – both of which are photosensitization syndromes – was found on Galenia procumbens in the Karoo, and described as Leptosphaerulina chartarum Cec. Roux (Roux 1986). The genus Togninia Berl. was recently linked to Phaeoleuconium W. Gams, Crous & M.J. Wingf., which was shown to be one of the causal organisms of Petri disease of grapevines (Mostert et al. 2003).

Many reports were published as part of the New and Interesting Fungi series in Bothalia, which later moved to the South African Journal of Botany (Van der Linde & Van Warming 1989). Other work included a revision of the South African Hysteriaceae (Van der Linde 1992). Johannes P. van der Walt, who was associated with the Centre of Scientific and Industrial Research (CSIR) made an enormous international contribution to the knowledge of yeast taxonomy with numerous publications on the distribution and diversity of South African fungi. Now retired, J.P. van der Walt contributed to the description of 81 new ascomycetous teleomorphs and anamorphs (14 genera). Some of these species are still known only from South African isolates.

Subsequent to the late 1990’s (Eicker & Baxter 1999), the relative dormancy in activities on ascomycetous fungi following Doidge (1950) became broken by a steady flow of contributions by plant- and forest pathologists (Agricultural News 1990), with the genera Ophiostoma Syd. & P. Syd., Ceratocystis Ellis & Halst. (Marais & Wingfield 2001, Roux et al. 2001a) and Mycosphaerella (Crous 1998, Crous & Braun 2003, Crous et al. 2004a, b) receiving particular attention. Plant-pathogenic ascomycetes occurring on Proteaceae and Restionaceae also received considerable attention, with the description of numerous new species and genera (Taylor & Crous 2000, Lee & Crous 2003a, c, d, Lee et al. 2003, 2004a). Saprobic ascomycetes occurring on Proteaceae litter, however, were less intensively studied (Lee & Crous 2003a, b, Lee et al. 2005). Contributions from other South African scientists included L. Korsten, F. Wehner, N. McClaren, B. Flett, N. Labuschagne and G. Thompson, who added valuable information pertaining to distribution records, host preferences and new disease reports.

Some ascomycete genera have received considerably more attention than others. One such genus is Mycosphaerella. Doidge (1950) listed 21 species of Mycosphaerella, and more than 100 cercosporoid anamorph species. A revision of species in this complex commenced in the early 90’s, with the description of numerous new taxa from indigenous and exotic hosts (Crous & Braun 1994, Morris & Crous 1994, Crous & Braun 1995). The cercosporoids occurring in South Africa were treated by Crous & Braun (1996a), who listed 159 species from diverse hosts. Taxa occurring on Proteaceae were treated by Taylor and co-workers in a series of papers focusing on Mycosphaerella, and anamorph-genera such as Phaeoleuconium Rangel, and Batcheloromyces Marasas, P.S. van Wyk & Knox-Dav. (Taylor & Crous 1999, Taylor et al. 1999). Other than Proteaceae, the Myrtaceae has also received some attention. Species of Mycosphaerella occurring on Eucalyptus were treated in several papers by Crous and co-workers (Crous & Wingfield 1996, Crous 1998, Crous et al. 2004a; Hunter et al. 2004a, b), listing 17 odd species on Eucalyptus in South Africa. The genus Syzygium, of which S. cordatum is indigenous to South Africa, was also investigated, revealing four species of Mycosphaerella on this host (Crous & Sutton 1997, Sutton & Crous 1997, Crous 1999). Given the exceptional Mycosphaerella species richness on hosts in the Proteaceae and Myrtaceae, it can be assumed that numerous species await description once leaves of other hosts are studied in more detail.

The genus Botryosphaeria and associated anamorph-genera have received considerable attention in recent years (Denman et al. 2000). Specific papers have addressed species occurring on hosts such as Eucalyptus (Smith et al. 2001, Slippers et al. 2004a–d), Proteaceae (Denman et al. 2003), Vitis vinifera (Van Niekerk et al. 2004a), Syzygium (Pavic & et al. 2004), Southern Hemisphere conifers (such as Widdringtonia) (Slippers et al. 2005b), various fruit trees (Slippers et al. 2006) and Mangifera indica (Slippers et al. 2005a), to name but a few. These studies once again indicate
that there are numerous unknown species of the \textit{Botryosphaeriaceae} in the Southern Hemisphere, and specifically in South Africa, awaiting description.

A suite of recent studies have focused on species that have traditionally been treated in the genus \textit{Cyphonectria} (Sacc.) Sacc. & D. Sacc. (Myburg et al. 2004a, b, Gryzenhout et al. 2004, 2005a, b, 2006 – this volume). These investigations arose from the first discovery of the serious \textit{Eucalyptus} stem pathogen \textit{Cyphonectria cubensis} (Bruner) Hodges in South Africa (Wingfield et al. 1989). The various studies, strongly supported by DNA sequence comparisons, have shown that \textit{Cyphonectria} is a genus restricted to the Northern Hemisphere (Myburg et al. 2004a, b). Related fungi occurring in Southern Hemisphere countries including South Africa, reside in various genera such as \textit{Chrysoporthe} Gryzenh. & M.J. Wingf. (Gryzenhout et al. 2004), \textit{Microthia} Gryzenh. & M.J. Wingf., \textit{Holocryphia} Gryzenh. & M.J. Wingf. (Gryzenhout et al. 2006), \textit{Rostraeurum} Gryzenh. & M.J. Wingf. (Gryzenhout et al. 2005a) and \textit{Amphilioa} Gryzenh., Glen & M.J. Wingf. (Gryzenhout et al. 2005b). New species and genera have also been discovered that are closely related to \textit{Cyphonectria}, such as \textit{Celopothere dispersa} Nakab., Gryzenh., J. Roux and M. J. Wingf. (Nakabonge et al. 2006 – this volume).

\textbf{Hyphomycetous fungi:} A cursory look through Doidge (1950) reveals that none of the earlier collectors in South Africa took particular note of hyphomycetes. Of the total of 4748 species that she listed, a mere 18.5 \% represented asexual forms. Subsequent studies comprised comprehensive inventories of the genera \textit{Fusarium} Link (Marasas et al. 1988), \textit{Penicillium} Link (Schutte 1992), \textit{Aspergillus} Link (Schutte 1994), entomophagous fungi (Rong & Grobbelaar 1998), dematiaceous fungi (Sinclair & Eicker 1985, Sinclair et al. 1983, 1985, 1987, 1990, 1994), and nematode-trapping fungi (Gorter 1993b). A review of \textit{Cercospora} Fresen. and similar fungi (Crous & Braun 1995), revision of the genus \textit{Cylindrocladium} Morgan and related genera (Crous & Wingfield 1993, 1994, Crous 2002), and differentiation of species of \textit{Bipolaris} Shoemaker, \textit{Exserohilum} K.J. Leonard & Suggs and \textit{Curvularia} Boedijn (Rong 2002) was compiled mostly from specimens in PREM.

The bulk of subsequent studies are miscellaneous reports of fungi from crops and animal feeds such as lucerne (Thompson 1985), \textit{Cenchrus ciliaris} pastures (Bezuidenhout 1977), natural Karoo pastures (Roux 1985), as well as toxigenic representatives of \textit{Fusarium} (Kellerman et al. 1972, Marasas et al. 1976) and \textit{Pithomyces} Berk. & Broome (Marasas & Schumann 1972, Kellerman et al. 1980), and various synnematous and other hyphomycetes (Rou et al. 1993, Roux et al. 1995, Jacobs et al. 2001). Other genera that received attention include \textit{Graphium} Corda (Jacobs et al. 2003b), \textit{Leptographium} Lagerb. & Melin (Wingfield & Marasas 1980, 1983, Wingfield 1985, Zhou et al. 2001), \textit{Cladosporium} Link (Braun et al. 2003, Surridge et al. 2003), \textit{Phialocephala} W.B. Kendr. (Jacobs et al. 2003a), and cercosporoid fungi (Crous & Braun 1996a, b, Pretorius et al. 2003). Several unique hyphomycetes were also reported from \textit{Proteaceae} and \textit{Restionaceae} in the fynbos (Wingfield et al. 1988, Me’nik et al. 2004, Lee et al. 2004b).

Specific mention should be made of the work of Marasas on the taxonomy of the toxigenicity and phytopathologically important genus \textit{Fusarium}, including soil surveys (Rheeder & Marasas 1998), and the description of numerous new species such as \textit{Fusarium andiyazi} Marasas, Rheeder, Lampr., K.A. Zeller & J.F. Leslie (Marasas et al. 2001), and \textit{F. thapsinum} Klittich, J.F. Leslie, P.E. Nelson & Marasas (Klittich et al. 1997). Similarly studies on the mycota of proteaceous fungi by Crous and co-workers (Crous et al. 2004a) have been very extensive.

Eyespot disease of wheat received considerable attention, with the causal organism originally being ascribed to \textit{Cercospora} Sacc., then \textit{Pseudocercospora} Deighton, and \textit{Ramulispora} Miura (Robbertse et al. 1995). Crous et al. (2003) erected the genus \textit{Helgardia} Crous & W. Gams to accommodate these cercosporoid anamorphs, while their discomyctete telemorphs were placed in the genus \textit{Oculimacula} Crous & W. Gams. Schroers et al. (2005) recently characterised the hyphomycetes associated with guava wilt, and identified the causal organism as a species of \textit{Nalanthamala} Subram.

Hyphomycetes from \textit{Vitis vinifera} have been intensively studied. Halleen et al. (2004) treated the \textit{Cylindrocarpin} Wollenw. complex associated with black foot disease, and introduced a new genus, \textit{Campyllocarp} Halleen, Schoers & Crous. Crous et al. (1996a) erected the genus \textit{Phaeoacremonium} for species associated with grapevine decline disease of grapevines and human infections, while Crous & Gams (2000) described the genus \textit{Phaeomonilia} Crous & W. Gams as the main causal organism of Petri disease.

Species of \textit{Cylindrocladium} Morgan (teleomorph: \textit{Calonectria De Not.}) (Hypocreales) are common in tropical and subtropical regions of the world, and cause disease problems on a wide range of hosts. Schoch et al. (2000) placed telemorphs of \textit{Cylindrocladiella} Boesew. in \textit{Nectricladiella} Crous & C.L. Schoch. In subsequent years Schoch & Crous (1999) reported \textit{Cylindrocladium spathiphyllyi} Schuolt., El-Gholl & Alfiery as causing Cylindrocladium root and petiole rot of \textit{Spathiphylly}, while Schoch et al. (1999) resolved the \textit{Cylindrocladium candelabrum} Viégas species complex, describing the common soil-inhabiting species in South Africa as \textit{C. pauciramosum} C.L. Schoch & Crous. In a recent monograph of \textit{Cylindrocladium} and allied genera, Crous (2002) reported six \textit{Cylindrocladium} species and five \textit{Cylindrocladiella} species from South Africa.

\textbf{Coelomycetous fungi:} In the Doidge era, investigators often recorded coelomycetes only incidentally, usually alongside their sexual state. Because they were mainly found on plant-pathological specimens, those that were most often reported were commonly occurring members of the genera \textit{Colletotrichum} Corda, \textit{Phyllosticta} Pers. 

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and *Pestalotia* De Not. (Doidge 1950). At this time there was a tendency to name taxa as new if they were found on new substrates. Many of these names would not hold up when judged with robust systematic techniques currently applied.

Many coelomycte reports were done from animal feed implicated in poisonings or other maladies in farm animals i.e. *Phomopsis leptostroftomiformis* (J.G. Kühn) Bubák (Van Warmelo et al. 1970) on lupins, *Tiarosporella Höhn.* (Sutton & Marasas 1976), *Colletotrichum* (Baxter et al. 1983, 1993), *Urohendersonia platensis* Spec. (Roux & Van Warmelo 1989), and *Bartalnla robillardoides* Tassi (Roux & Van Warmelo 1990).

*Paraconiothyrium mimitans* (W.A. Campb.) Verkley was investigated as an antagonist of the devastating pathogen, *Sclerotinia sclerotiorum* (Lib.) de Bary (Phillips 1985). Possibly the most notorious coelomyctes in South Africa are *Phyllosticta citricarpa* (McAlpine) Aa, the cause of black spot of oranges (Meyer 1970), *Termitomyces* and intoxication of sheep (Rheeder 1951 to 1958, dealing with the monographic work on resupinate and stereoid Hymenomycetes, including the monograph on *Termitomyces* in 1951a, b, 1954, 1958, 1965) and *Stenocarpella maydis* (Berk.) B. Sutton (syn. *Diplodia zeae* van der Bijl) causing black rot of maize and intoxication of sheep (Rheeder et al. 1990). Other genera that received attention include *Coniella Höhn.* and *Pilidiella Petr.* & *Syd.* (Van Niekerk et al. 2004b), *Colletotrichum* (Lubbe et al. 2004), *Harknessia Cooke* (Crous et al. 1993, Lee et al. 2004a), *Dothistroma Hulbary* (Barnes et al. 2004), the *Fusicoccum/Diplodia* anamorphs of *Botryosphaeria* (Denman et al. 2000, Slippers et al. 2004a–d), and *Phomopsis* (Sacc.) Bubák (Smit et al. 1989a, b, 1996a, b, Mostert et al. 2001, Van Niekerk et al. 2005). Coelomycteous fungi occurring in the fynbos also received some attention, namely those occurring on *Proteaceae* (Crous et al. 2004a) and *Restionaceae* (Lee & Crous 2003b).

**Basidiomycetes**

In early years, basidiomycetes such as the *Hymenomycetes* (McNabb & Talbot 1973, Talbot 1951a, b, 1954, 1958, 1965) and *Ustilaginales* (Doidge 1950) received some attention. Approximately 36 % of the fungi listed by Doidge (1950) are basidiomycetous. Eicker & Baxter (1999) present a good overview of work done on basidiomycetes from 1977 to 1999. Their publication provides references to studies on the genera *Phaeolus* (Pat.) Pat., *Pisolithus* Alb. & Schwein., *Termitomyces* R. Heim, *Amanita* Pers., *Chlorophyllum* Masssee, *Clathrus* P. Micheli ex L., *Hymenagaricus* Heinem., *Leptota* (Pers.) Gray, *Macropletiota* Singer, *Leucoagaricus* Looq, ex *Singer*, *Leucocoprinus* Pat., *Montagnea* Fr. and *Hymenochaete* Lév. Several new genera of heterobasidiomycetous yeasts were also newly described through the years by J.P. van der Walt and colleagues.

Some of the more extensive investigations were the monographic work on resupinate and stereoid Hymenomycetes and a series of papers between 1951 to 1958, dealing with *Stereum* Pers., *Lopharia* Kalchbr. & MacOwan, *Cymatoderma* Jungh. and the *Thelephoraceae* (Gorter 1979). Early investigations also included a series of papers on tree pathogens and wood-destroying *Hymenomycetes* (Van der Westhuizen 1972).

Some revisionary work has been done on collections of certain taxa at PREM in the course of monographic work at the University of Buenos Aires, Argentina, namely species of *Hymenochaete* Lév. (*Hymenochaetaceae*) (Job 1987). Limited information is available about the *Geasteraceae* (Coetzee & Eicker 1994, Coetzee & Van Wyk 2003) but a revision of the South African Stereum species, and the *Geasteraceae* (earth stars), which will to a large part rely on material lodged in PREM, is in progress (J. Coetzee, pers. comm.).

Significant contributions following Doidge were made by D.A. Reid from the Royal Botanic Gardens Herbarium, Kew. Reid reappraised the type and authentic specimens of species of *Basidimycota* described from South Africa in PREM (Van der Westhuizen & Eicker 1994), the van der Bijl Herbarium (now housed at PREM), and elsewhere (Reid 1975). This has been the foundation for his documentation of South African mushrooms in collaboration with Albert Eicker from the University of Pretoria. An equally productive partnership has provided us with a scientific guide to our edible and poisonous mushrooms and other large fungi. In 1994, G.C.A. van der Westhuizen’s lifetime of mycological research and photography culminated in a field guide (*Van der Westhuizen & Eicker 1994*), with excellent colour photographs of some 160 species of local macrofungi. The most recent studies include DNA phylogenetic data, like that published on species of *Termitomyces* R. Heim (Botha & Eicker 1991a, b, De Fine Licht et al. 2005).

Studies during the early part of the last Century reported *Armillaria mellea* (Vahl : Fr.) P. Kumm. in South Africa (Pole Evans 1933, Kotzé 1935, Bottomley 1937). These were largely associated with an expanding plantation forestry industry and the fact that this fungus resulted in tree death. A series of recent studies have shown that the fungus killing trees in this country is *A. fuscipes* Petch (Coetzee et al. 2000) and that there are probably at least two other species occurring in neighbouring countries such as Zimbabwe (Mwenje et al. 2003). Intriguingly, it has also been shown that the Northern Hemisphere species, *A. mellea* was introduced into South Africa, probably by the early Dutch settlers (Coetzee et al. 2001). Likewise, the Northern Hemisphere species *A. gallica* Marxm. & Romagn. has recently been recorded from dying *Protea* plants in the Kirstenbosch botanical gardens (Coetzee et al. 2003).

G.L.I. Zundel of the U.S.A., who collaborated with Pole Evans and Doidge in describing and re-investigating material found by South African mycologists, extensively studied local smut fungi. K. Vánky in Germany radically changed the taxonomic study of this group of fungi by advocating the use of morphological characters obtained by germinating spores (Vánky 1997, 1999a, b, 2000a–b, 2001). It is problematic when we apply these methods to old herbarium specimens, however, because their spores have lost the ability to germinate. One of our earliest records and most striking smuts is maize boil smut, *Ustilago maydis* (DC.) Corda [= *U. zeae* (Link) Unger].
Rust fungi (Uredinales): Most of the rust fungi known from southern Africa were treated and described by Doidge (1927, 1928, 1939, 1940, 1948a, b). This suite of papers remain the basis for identification of these fungi in southern Africa, and are relevant to the whole of the African continent. All known species were listed in Doidge (1950). A total of 474 species are listed from southern Africa, including 145 anamorphs.

Since Doidge (1950), nine species have been transferred to other genera, and a further 30 species names have been reduced to synonymy. In addition, eight anamorph species of Aecidium Pers. have been connected to their telemorphs (Kleinjan et al. 2004), and three have been demonstrated to be endocyclic (Wood 1998, 2004, Wood & Crous 2005), whilst 11 anamorph species of Uredo Pers. have been connected to their telemorphs. Many of these changes were published in Jørstad (1956) and various publications summarised in Cummins (1971). It can be expected that the status of many more names will change as further taxonomic studies progress (Van Reenen 1995).

Since Doidge (1950), a number of new species have been described by G. B. Cummins and H. Gjærum in various papers, none dealing exclusively with species from the region (Cummins 1960, Gjærum & Reid 1983, 1998, Gjærum 1988a, b, 1999). More new species have been described recently (Shivas 1991, Wood 2002, Mennicken et al. 2003, Mennicken & Oberwinkler 2004, Mennicken et al. 2005a, b, Wood & Crous 2005, Wood & Scholler 2005). Taking these above-mentioned changes into account, there are currently 537 species of rust fungi, representing 40 genera and 10 families.

Why then are there relatively few rust species recorded in just the last 5 years (Wood 2002, Mennicken et al. 2003)? There are a number of possible explanations for this, the most likely including: (1) Much of South Africa, as well as Botswana and Namibia is semi-arid to desert. The low rainfall associated with these areas would restrict opportunities available to rust fungi to infect their hosts, which could result in the lower diversity of rust fungi. (2) There are very few rust species recorded from the fynbos and succulent Karoo biomes, despite the high plant diversity for which these biomes are well known. The high plant species diversity is largely produced by few but speciose genera and families with high turnover of species over short distances (Linder et al. 1992, Goldblatt 1997).

The rust fungi in South Africa tend to either occur on one or a few closely related plant species with a large distribution, or on numerous related plant species, many of which have limited distributions. Endophyllum osteospermi (Doidge) A.R. Wood, E. elytropappi (Henn.) A.R. Wood & Crous (Wood & Crous 2005) and Uromyces kentaniensis Doidge are examples of the former, whilst U. bulbisus Massee, U. ixiæ (Lév.) G. Winter and Puccinia byliana Dippen. are examples of the latter (A. Wood, unpubl. data). The greatest diversity of rust fungi in South Africa is in the eastern parts, associated with a greater amount of summer rain. There the ratio of rust fungi to plant species is probably approximately the same as for Zimbabwe, which is ecologically similar.

Zygomycota

Only seven genera of the Mucorales were noted by Doidge (1950), one of which, Haplosporangium Thaxt., has not since been found. They include the important saprotrophic species, identified early on, such as the ubiquitous Rhizopus stolonifer (Ehrenb.) Vuill. – listed as R. nigricans Ehrenb., – which causes post-harvest decay, particularly in sub-tropical fruit. A subsequently recorded species, R. oryzae Went & Prins. Geerl., has been associated with mycoses in humans. It is the most commonly found member of this group, particularly in fodder samples. During the course of several years, PREM has supplied numerous cultures of Mucorales, and participated in research focused on metabolite studies. Certain strains produce gamma linoleic acids (Botha et al. 1995) culminating in patenting of a fermentation process.

By 1999 the number of genera from this group known to South Africa had risen to 20 (Roux 1996). A study on Trichomycetes, parasites or commensals in the digestive tract of arthropods, yielded several new records and new species (Gorter 1993a).

Lichen-forming and lichenicolous fungi

In comparison with other fungal groups, the macrolichens of South Africa in particular are relatively well-studied, though much needs to be done on the microlichens and lichenicolous species. Early records were compiled in Stizenberger (1890–1895), but the major synthesis to date is that of Doidge (1950). Extensive collections were made by Elise Esterhuysen (1912–) in the late 1940s–1950s (material in the Bolus
Herbarium, University of Cape Town), but the principal contributions have been by Ove Almborn (1914–1992) from Lund (Sweden) and Franklin A. Brusse (1951–) who was for some years on the staff of the National Herbarium in Pretoria. Almborn specialized on *Teloschistites* Norman (Almborn 1989) but travelled extensively in the country, for example spending 5 mo there in 1953 (Almborn 1966), analyzing distribution patterns (Almborn 1987, 1988), and also issued an important exsiccate, “Lichenes Africani”; this comprised six fascicles from 1956–1991 including 150 numbers. Brusse had his major interest in the Parmeliaceae and described many species new to science, especially effigurate-crustose species on rock later placed in the endemic genus Karowia Hale (the species known from Australia appear to belong elsewhere). Numerous other lichenologists have visited and collected, amongst the most notable being Gunnar Degelius (1903–1993) who specialized in *Collemataceae* (Degelius 1974), Ingvar Kärnefelt (University of Lund) with a special interest in *Teloschistaceae*, Leif Tibell who specializes in caliciaceous groups (who visited with colleagues from the University of Upsala in 1997), and Mason E. Hale jr (1928–1990) who described numerous species and several new genera in the Parmeliaceae (e.g. Hale 1986, 1988), although not all his new genera have yet been evaluated by molecular methods. Much collecting was also carried out during the International Association for Lichenology’s field meeting in Namibia and South Africa in 1986, but the results from that excursion have not been synthesized. Some revisionary studies have been carried out based on the collections of these and other lichenologists, for example the monograph of *Diploschistes* Norman in South Africa by Guderley & Lumbsch (1996).

More recently, as a part of the Biota-So5 project funded by the German government, an extensive survey of lichen biodiversity from the Cape Province to northern Namibia is underway, the leading researcher involved being Tassilo Feuerer (University of Hamburg). In addition, an international expedition led by Ana Crespo (Universidad Complutense de Madrid) and focussing on the Parmeliaceae made about 750 collections in May–June 2005 from the Western Cape north to the Namibian border.

Sadly there is no systematic lichenologist resident and active in South Africa today. Further, there is no modern critical checklist available, but a preliminary list compiled from the literature (www.biologie.uni-hamburg.de/checklists/africa/southafrica) contained 1716 species as of 1 March 2005. This list is a valuable basis for future work but is very preliminary and includes both many early names copied from the literature whose position and status needs to be reassessed, and others that have been revised but have yet to be updated from other literature. A reasonable estimate of the total number of lichen-forming species to be expected, by comparison with checklists from other regions of the world with similarly diverse climatic regions and rock types (Will-Wolf et al. 2004) would be about 2000 (excluding lichenicolous fungi).

In comparison to the flowering plants, only a handful of genera appear to be endemic, notably *Combea* De Not. and *Karowia* s. *str.*, with others requiring reassessment, for example *Almbornia* Esslinger, *Canomaculina* Elix & Hale, *Namakwa* Hale, and *Xanthomaculina* Hale. In contrast, there are many endemic species, especially in the Parmeliaceae and the Teloschistaceae. The lichen assemblages are very distinctive in different parts of the country, as discussed by Almborn (1988), comprising at least eight phytogeographic categories: ubiquitous, steppe and desert (e.g. Namaqualand, Karoo), montane (over 1000 m alt.), oceanic (e.g. Table Mountain, Drakensberg Mountains), tropical-oceanic (e.g. northern KwaZulu-Natal, Mpumalanga), maritime (on coastal rocks), and endemic.

Lichenicolous fungi, fungi obligatory on lichens as pathogens, commensals or saprobes, have hardly been reported from South Africa. None are included in the 2005 preliminary checklist, not even representatives of such ubiquitous genera as *Abrothallus* De Not., *Lichenonion* Petr. & Syd., *Polycoccum* Saut. ex Körb., and *Stigmidium* Trevis. There are, however, some scattered records, such as that of *Lichenostigma cosmopolites* Hafellner & Calat. (Hafellner & Calatayud 1999) which is very common on *Xanthoparmelia* (Vain.)

### Table 1. Number of recorded rust fungi (*Uredinales*) as a percentage of the number of vascular plants in various countries.

| Country          | No. rust species | No. plant species | Rusts as % of plants | Reference                  |
|------------------|------------------|-------------------|----------------------|----------------------------|
| South Africa     | 397              | 23420             | 1.7 %                | A. Wood, unpubl. data      |
| Zimbabwe         | 143              | 4440              | 3.2 %                | A. Wood, unpubl. data      |
| Hawaii           | 22               | 1897              | 1.1 %                | Gardner (1994)             |
| Great Britain    | 238              | 1443              | 16.5 %               | Wilson & Henderson (1966)  |
| Norway           | 265              | ca. 2000          | 13.3 %               | Gjærum (1974)              |
| Japan            | 790              | 4022              | 19.6 %               | Hiratsuka et al. (1992)    |
| Canadian arctic  | 53               | 325               | 16.3 %               | Parmelee (1989)            |
| Guatemala        | 416              | ca. 8000          | 5.2 %                | Hennen & McCain (1993)     |
| El Salvador      | 140              | ca. 2500          | 5.6 %                | Hennen & McCain (1993)     |

Note: The number of rust fungi is provided as a percentage of the number of vascular plants in various countries.
Hale species in the country (D.L. Hawksworth, pers. obs.), and an undescribed Polycoccus on Karoowia adhaerens (Nyl.) Hale (Váčzi & Hawksworth 2001). Many lichenicolous fungi were collected during the visit of Ana Crespo’s group in 2005, but have yet to be fully identified. In comparison with what is known of the species richness of lichenicolous fungi compared with the number of potential host lichen species, for example 403 vs. 1677 lichen species in Great Britain and Ireland (Hawksworth 2003), around 475 species would seem to be a reasonable estimate of the number to be expected in South Africa.

**Oomycetes**

Fifteen species of Phytophthora de Bary from 74 different hosts have been recorded from eight southern African countries during the period 1941 to 2001. Typical disease symptoms were damping off, root rot, stem rot, stem canker, crown rot, tip blight, leaf rot and fruit rot. Records for Pythium Pringsheim species date from 1931 to 2004. Twenty species of Phytophthora have been reported from 65 different hosts, and representative disease symptoms were damping off, seedling blight, root rot, stem rot (foot rot), crown rot (heart rot), fruit rot, tuber rot and soft rot.

**Phytophthora:** The first detailed study of Phytophthora species with associated hosts and distribution patterns in South Africa, was done by Wagner (1935, 1941) describing *P. cactorum* (Lebert & Cohn) J. Schröter, *P. cinnamomi* Rands, *P. citrophthora* (R.E. Smith & E.H. Smith) Leonian, *P. cryptogea* Pethybridge & Lafferty, *P. infestans* (Montagne) de Bary, *P. nicotianae* Breda de Haan and *P. syringae* (Klebahn) Klebahn. Mes (1934) and Wijers (1937) reported *P. cactorum* on various hosts and included descriptions and disease symptoms. Other studies confirmed species identification (Wager 1931, van der Merwe et al. 1972). Descriptions of various Phytophthora species from different vegetable and ornamental crops were recorded by Thompson (1981), Thompson & Phillips (1988), Ferreira et al. (1991), Thompson & Naudé (1992) and Thompson et al. (1994). Morphological and molecular methods (RFLPs of total DNA) were used by Botha (1993) to confirm species identity of *P. nicotianae* on tree lucerne. Linde et al. (1997) applied isozymes to distinguish two separate populations of *P. cinnamomi*, determining genotypic variation within A1 and A2 isolates, and established that sexual reproduction was rare or absent in South African isolates. Linde et al. (1999) used both RAPDs and RFLPs to assess genotypic diversity and reveal DNA polymorphisms in South African and Australian isolates of *P. cinnamomi*. Von Maltitz & von Broembsen (1984) reported *P. pomi* Foister from onions, followed by *P. citricola* Sawada causing shoot tip blight of lemons in propagation tunnels (Von Maltitz & von Broembsen 1985).

Comprehensive disease surveys, but with limited taxonomic treatment, were performed by Marais (1979) in the Western Cape Province, surveying grapevine rootstock diseases. Von Broembsen (1984) did an extensive survey of *P. cinnamomi* root rot in indigenous fynbos, and from the major catchment rivers in the Western Cape. Thompson (1987, 1988) surveyed alfalfa in various provinces for *P. medicaginis* E.M. Hansen & D.P. Maxwell and *P. drechsleri* Tucker. Linde et al. (1994a, b) surveyed the major commercial forestry areas in South Africa for root rot caused by oomycetes, while Thompson et al. (1995) surveyed citrus roots for *Phytophthora* and *Pythium* in the Mpumalanga and Limpopo Provinces. Labuschagne et al. (2000) reported *P. capsici* Leonian causing wilt of pumpkin, and stem and root rot of tomato (Labuschagne et al. 2003). McLeod et al. (2001) conducted an extensive survey of Late Blight (*P. infestans*) in the major potato production areas in South Africa, determining mating type and using various molecular markers to characterise isolates.

**Pythium:** The first major contribution by Wager (1931) consisted of several species descriptions and disease symptoms on hosts. Additional species descriptions, temperature-growth measurements and hosts, was also reported by Wager (1941). Doidge (1950) and Doidge et al. (1953) compiled the host range of numerous Pythium species, and this compilation was updated by Gorter (1977, 1982) and Crous et al. (2000b). Darvas et al. (1978) and Darvas (1979) added further records of *Pythium* species with host records. Scott et al. (1979) and Scott (1987) made a major contribution with regard to the occurrence and disease symptoms of *Pythium* species from various small grain crops. An extensive overview of all recorded *Pythium* species in South Africa from 1926 to 1989 was compiled by Denman & Knox-Davies (1992) and included distribution, host range and species diversity. A detailed taxonomic description of various *Pythium* species associated with vegetables was reported by Botha & Coetzee (1996) and *Pythium proliferum* W.A. Campbell & Hendrix causing wilt of *Rhododendron* sp. (Botha & Crous 1992). *Pythium* species have also been associated with grapevine (Marais 1979, 1980), medics (Lamprecht et al. 1988), lucerne seedlings (Denman & Knox-Davies 1992), pines and eucalypts (Linde et al. 1994a, b) and lettuce (Labuschagne et al. 2002). Reports of asexual, sporangial isolates of *Pythium*, viz. G-group, F-group, T-group and P-group as well as homothallic species, e.g. *P. coloratum* Vaartaja, *P. irregularare* Buysman, *P. myriotylum* Drechsler, *P. perplexum* Kouyeas & Theohari, *P. dissotocum* Drechsler and *P. spinosum* Sawada, have been reported from closed hydroponic systems in South Africa (Labuschagne et al. 2001, 2002, Gull et al. 2004, Tesfaendrias et al. 2004).

**MISCELLANEOUS REPORTS FROM LITTLE-STUDIED NICHEs**

Reference is made by Eicker & Baxter (1999) to fungi recorded in particular ecological niches. These include a number of publications of fungi from aquatic habitats such as fast-flowing rivers, submerged woods and twigs in stagnant freshwater habitats, wood invading
fungi in marine waters, estuaries and from leaves in a mangrove. Non-aquatic habitats included phylloplane fungi, foliicolous fungi, airspora over pastures, coprophilous fungi from domestic, captivated and wild animals, fungi associated with cultivated mushrooms, undisturbed soil populations, fungi for the control of invasive plants and from plant litter. From 1955 to 1984 approximately six publications addressed reports of fungi causing human and animal diseases. These include a study on mycoses, dermatophytes and fungi causing subcutaneous infections.

Fungi associated with mycorrhizal associations have also received some attention in South Africa. A significant contribution was the ecological survey of arbuscular mycorrhiza made by Wehner in 1976 (Eicker & Baxter 1999). Subsequent studies include recordings of *Acaulospora laevis* Gerd. & Trappe, and investigations on fynbos soils by Mitchell, Reid, Straker, van Greunng, Sinclair and later during a survey of the investigations on fynbos soils by Mitchell, Reid, Straker, van Greunng, Sinclair and later during a survey of the fungal pathogens on *Pinus* by Van der Westhuizen and Eicker (Eicker & Baxter 1999).

Several papers were published on fungal endophytes. Crous et al. (1995a) listed 55 endophytes from *Triticum aestivum*, while Serdani et al. (1998) treated the endophytic *Alternaria* Nees species associated with core rot of apples. Kriel et al. (2000) provided an overview of foliar endophytes in *Gymnospermae*, and Mostert et al. (2000) treated the endophytic *Phomopsis* spp. occurring in grapevines. Smith et al. (1996) treated endophytic *Botryosphaeria* species in *Pinus* and *Eucalyptus*. Swart et al. (2000) reported on the fungal endophytes in cultivated *Protea*, *Leucospermum* and *Leucadendron*, and Taylor et al. (2001) treated the endophytes occurring in *Protea* spp. grown in the wild.

Several papers focused on leaf-litter fungi in general (Sinclair & Eicker 1985, Sinclair et al. 1985, 1987, Crous 1990, Sinclair et al. 1990, 1994), or on specific hosts such as *Syzygium cordatum* (Crous et al. 1995b), *Podocarpus* (Crous et al. 1996b), and *Eucalyptus* (Crous et al. 1990a, Crous & van der Linde 1993, Crous et al. 1997).

Fungi on commercially important exotic hosts such as *Eucalyptus*, *Pinus* and *Acacia* have been studied in detail. Crous et al. (1990b) listed the shoot and needle diseases occurring on *Pinus* spp., while the leaf pathogens occurring on *Eucalyptus* were treated Crous et al. (1989). Vlijoen et al. (1992) provided a summary of the fungal pathogens on *Pinus* and *Eucalyptus* seedlings in nurseries in South Africa. Crous (1998) treated the species of *Mycosphaerella* occurring on *Eucalyptus*, and listed 14 species from South Africa, while Slippers et al. (2004d) treated the *Botryosphaeria* spp. occurring on this host. Roux & Wingfield (1997) treated the fungi causing diseases of *A. mearnsi*, and found various species of fungi, including *Fusarium graminearum* Schwabe and *Ceratocystis albifundus* M.J. Wingf., De Beer & M.J. Morris to be associated with a wilt disease of this host (Roux & Wingfield 1997, Roux et al. 2001a, b).

### FUNGI ON INDIGENOUS HOSTS: FABULOUS FYNBOS FUNGI AS A CASE STUDY

The dicotyledonous *Proteaceae* (proteas) and monocotyledonous *Restionaceae* (restios) are two of the most prominent plant families in the Southern Hemisphere. In South Africa the majority of the species are confined to the south-western corner of the country in 90 000 km², the so-called “Cape Floristic Region” or “Cape Floral Kingdom”. Proteas are represented by 320 species, of which 96 % are endemic to the region (mostly members of the genus *Protea*) and restios by 330 species, of which 94 % are endemic to the region (Goldblatt & Manning 2000).

In a study aimed at exploring the saprobic (litter) microfungi inhabiting these two families, nature reserves and botanical gardens were visited over a 2-year period (2000–2001). About 580 fungal strains were isolated from 34 restio species (representing 15 genera), which consists of approx. 150 fungal genera and 180 species. Another 580 fungal strains were isolated from 43 protea species (representing five genera), which consists of approx. 120 fungal genera and 185 species. A total of about 230 fungal genera were isolated, of which 190 were confined to either the one or the other host family, while 40 fungal genera occurred on both families. A total of 380 were identified to species level, of which 355 were restricted to one or the other family, while 25 species occurred on both families (Fig. 4).

Saprobic fungi are different from plant-pathogenic fungi, and do not show a strong host specificity, but rather have a broad range of host recurrence (or host preference) such as mono/dicotyledonous plants in the tropics or gymno/angiosperms in temperate forests (Lodge 1997, Yanna et al. 2002). A well-studied group in our collections, hyphomycetous fungi, showed a high degree of host-recurrence (Lee et al. 2004b). The differences in physical textures and chemical compositions of tissues between the two host groups, which reflect their taxonomic distance and different lineage, might be a cause for a higher degree of host-recurrence. In total only 7 % of the species occurred in both host groups. This again complies with the view of Polishook et al. (1996) that much of the host-recurrence in litter fungi is probably related to physical and chemical characteristics of leaves rather than host-specificity.

![Fig. 4. Numbers of fungal taxa associated with two plant groups: Proteaceae (proteas) and Restionaceae (restios).](image-url)
Pirozynski & Hawksworth (1988) argued that over 50% of the fungi inhabiting microhabitats have possibly evolved in a very close relationship with their host. Inflorescences and infructescences are considered as miniature ecosystems, which accommodate different food chains and trophic levels (Zwölf 1979). Eighteen Protea infructescences were collected during this study, which revealed a unique composition of fungi (Lee et al. 2005).

The number of fungal species isolated from each collection varied depending on host plant habitat. For example, 38 fungal species were isolated from Brabejum stellatifolium (Proteaceae), which has a riverine habitat and thick twigs and branches. In contrast, only four species were isolated from Elegia filacea (Restionaceae), which grows in dry areas, and has culms of approx. 1 mm diam.

From these data we have found that there are at least three unique species of saprobic microfungi for each species of Proteaceae or Restionaceae thus far investigated (Fig. 5). However, we regard this as a minimal estimate because of the limitations of the damp-chamber isolation technique, and the undersampling of microhabitats such as infructescences.

**Fungi Associated with Insects**

Fungi associated with insects, ranging from parasitic to mutualistic associations, have been characterised in virtually all insect groups, and especially in families such as Isoptera, Hymenoptera, Homoptera, Coleoptera, Diptera and others (Vega & Blackwell 2005). Despite significant data pointing to the ubiquity and novelty of the fungi involved in these associations, they are left out of most estimates of fungal diversity due to insufficient data. This lack of information is due to the difficulty of characterising these fungi based on traditional criteria and, in some cases, ignorance of their existence and importance. For example, a recent paper by Suh et al. (2004) reported over 200 undescribed species of yeasts from the guts of 27 families of beetles; a novel niche. Species accumulation curves showed that they had probably not exhausted even half of the unique species in their samples. These findings provide a tempting example of the potential fungal biodiversity that could exist in South Africa. Southern Africa has an estimated 17 433 recognised beetle species in 104 families, but this species number could well be 2–3 times higher (Scholtz & Chown 1995). Extrapolating from the data of Suh et al. (2004), this niche alone most likely harbour hundreds, if not thousands, of undescribed yeast species in South Africa. The diverse array of specialised parasitic fungi of arthropods is equally poorly known from South Africa (see Vega & Blackwell 2005, as example of the potential diversity). Ignoring this niche thus overlooks a significant portion of the fungal biodiversity of the region. The fact that it will have to be ignored in the current paper, highlights the need for more specific research focus on this area in South Africa and elsewhere.

One group of insect-associated fungi that has been better characterised than most, especially in the Northern Hemisphere, is that of the ophiostomatoid fungi with bark and ambrosia beetles (Six 2003, Kiritsis 2004). In South Africa, three Raffaelea Arx & Hennebert species have been described from two native ambrosia beetles (Scott & Du Toit 1970), while at least 11 ophiostomatoid species have been reported from introduced pine bark beetles (Zhou et al. 2001, 2006). Unfortunately the number of ambrosia and bark beetle species in South Africa has not been determined to date. Seven novel ophiostomatoid species have also been described from merely nine of the more than 300 Protea spp. in South Africa (Marais et al. 1998, Marais & Wingfield 2001, Roets et al. 2006). The morphology of the fungi and the wealth of insects present in protea infructescences suggest that the species from proteas are vectored by arthropods (Marais & Wingfield 2001). Five more, undescribed Sporothrix Hektoen & C.F. Perkins and Ophiostoma spp. were recently discovered (De Beer et al. 2005) growing on fungal combs in 13 termite mounds, representing only three of the at least 42 fungus-growing termite species (Macrotermiteinae) in Southern Africa (Uys 2002). These studies on ophiostomatoid fungi associated with beetles, Protea sp. (and their insects), as well as termites, suggest that the species richness of the ophiostomatoid fungi, and the interaction between arthropods and fungi in these niches, are under-explored.

Termitomyces spp. associated with some termite species are arguably one of the best known fungi among non-specialists in South Africa, as they are rather obvious, numerous and a well-loved delicacy. A number of species have been described from South Africa (Eicker & Baxter 1999). However, not all species of Termitomyces R. Heim associated with the 42 South African fungus growing termite species have been characterised. Thus, these fabulous fungi might be more diverse than current numbers suggest. Neither have the Xylaria Hill ex Schranks species associated with termite nests been characterised.

The introduction of the woodwasp Sirex noctilio has recently added one species to the list of South African fungal species, namely its mutualistic symbiont, Amylostereum areolatum (Fr.) Boidin (Slippers et al. 2003). These two organisms are currently causing significant damage to pine plantations throughout the country. This example
illustrates the role of exotic insects introducing more fungi to South Africa, potentially with disastrous consequences.

**Fungal Estimates for South Africa**

Hawksworth (1991) noted that the ratio between the number of vascular plants and fungi from all substrata in the British Isles, which is an intensively studied region on which he based his estimates, was around 1 : 6 using several different data sets. Using this ratio, the conservative estimate of 270 000 vascular plant species resulted in an estimate of 1620 000 species of fungi. If we accept that the 1.5 M estimated number of fungal species exist, we currently only know around 7 % of these (Hawksworth 2004). Other estimates vary, namely Finland was estimated to have a plant to fungus ratio of 1 : 4, while the U.S.A. was estimated at around 1 : 1 (Hawksworth 1991). Although likely numbers of fungi occurring on insects were not taken into account due to insufficient data, estimates were as high as 13.5 M fungal species (Hawksworth 1991).

Pascoe (1990) estimated that there could be at least ten times as many fungi as vascular plants in Australia, with 2.7 M species of fungi occurring world-wide. Smith & Waller (1992) estimated that there could be 1 M on tropical plants alone. Dreyfuss & Chapela (1994) considered endophytic fungi, a group easily forgotten, and estimated that 1.3 M taxa might exist in this niche alone. By studying palm fungi, Fröhlich & Hyde (1999) concluded that on this group of plants there was most likely a ration of 1 : 33 fungi per plant species. In Mexico, a study of macromycetes in pine-oak forests resulted in a ratio of 1 : 3.5 species of macromycetes. Hyde (1996) considered that there were approx. three pathogens, 10 saprobes and 100 endophytes for each species of palm, suggesting that the fungus to plant ratio could be as high as 1 : 26. Hyde et al. (1997) also reported that 75 % of all fungi collected on palms were new to science.

Some individual examples have revealed a surprisingly large number of fungi. For example, 117 species have been described from *Juncus roemerianus*, of which 68 were apparently new taxa (Kohlmeier & Volkmann-Kohlmeyer 2001). Hawksworth (1998) reported 92 species from *Urtica dioica* of which 17 appeared unique, and 55 on *Lantana camara*, of which 28 were host-specific. A further 893 fungi were reported from *Pinus sylvestris* (558 unique fungi if potential synonyms were taken into account), and 282 species on *Eucalyptus globulus*, of which 150 were not known from other eucalypts. Subsequently, Crous and co-workers have been describing more unique fungi from *E. globulus*, which suggests that the 282 figure reported by Hawksworth (1998) was an underestimate. So far only very few ecological niches and hosts have been thoroughly studied in South Africa.

The fungal biodiversity in southern Africa has been poorly studied to date, and no host has been thoroughly treated (e.g. all living plant parts: roots, stems, leaves, and litter, endophytes, epiphytes, and specific isolation techniques for specific fungal groups). Based on the lack of data, it is thus very difficult to estimate the number of unique fungi per host. However, by using moist-chamber incubation to culture saprobic fungi, Crous et al. (1996b) described four unique hypomycetes from *Podocarpus elongatus*. Other fungal groups were seen, but not treated, thus from this one host, and one fraction of a niche, the ratio is 1 : 4. By using the same technique to study hypomycetes on leaf litter of *Syzygium cordatum*, Crous et al. (1995b) described five unique saprobic fungi, while in later studies a further five unique plant pathogenic fungi were described from this host (Sutton & Crous 1997, Pavlic et al. 2004), which increases the ratio to 1 : 10, with several more host-specific fungi on this host awaiting description. In a study of the plant-pathogenic fungi occurring on *Proteaceae*, Crous et al. (2004a) reported six unique folicolous species from *Protea cynaroides*, suggesting a ratio of 1 : 6 as being an underestimate. Although these three hosts have not been fully studied, they provide a ratio of 4–10 unique fungi per host, suggesting that there could be an estimated seven unique species of fungi per indigenous host. Although it is highly unlikely that each host in each habitat would have seven unique species of fungi, many hosts might have some more, as this figure is an estimate based on a very incomplete examination of these hosts. Given that there are 24 500 species of plants in South Africa (Germishuizen & Meyer 2003), this estimate would mean that there could be 171 500 species of fungi, before taking numbers of insects into account. Based on this approach, however, the number of endemic fungi would be determined by the percentage endemic plants (and insects once taken into consideration). This ratio compares quite favourably to the ratio proposed by Hawksworth (1991), which was 1 : 6, Pirozynski (1972) which was 1 : 3–5, Pascoe (1990), which was 1 : 10, and Rossman (1994) which was around 1 : 4.

**To Collect, Study and Preserve the Basal Link**

South Africa is well-known for its botanical beauty and diversity, but here we have attempted for the first time to use its botanical diversity to estimate its fungal biodiversity. Based on the 1 : 7 ratio used above, we estimate that there could be as many as 171 500 species of fungi. This is definitely an underestimate, as no insect-associated fungi were taken into account, which alone makes a case that this estimate is inordinately conservative. Furthermore, given the high level of endemism found in the southern African flora, one would expect an equally high number of unique fungi. It is ironic, therefore, that only around 780 new species of fungi have thus far been described from South Africa (Figs 1–2). It is obvious therefore, that the study of South Africa’s unique, indigenous fungal biodiversity has never been regarded as a research priority. In the past almost no financial support has been
allocated to it from the various southern African funding bodies. In our text, some attention was given to the study of saprobic and plant-pathogenic fungi. This is, however, a simplification of the reality as many diverse fungi exist that have unique ecological niches and roles yet to be studied. What level of attention has been given to, for instance, anthropophilic fungi (infectious to man), aquatic fungi (aquatic habitats), bryophilos fungi (on bryophytes), coprophilous fungi (on dung), dermatophytes (on skin, hair nails), endolithic fungi (on rocks), entomogenous fungi (on insects), halotolerant fungi (tolerant to salt), hypogeous fungi (growing below ground), keratinophilic fungi (on feathers, horns), lichens (some studied, see Fig. 3), marine fungi (in marine and estuarine habitats), mesophilic fungi (growing between 10–40 °C), mycorrhhizal fungus (symbiotic with plant roots), mycoparasites (on other fungi), nemathopagous fungi (parasitic on nematodes), osmotolerant fungi (growing at high osmotic pressure), psychrophilic fungi (at < 10 °C), pyrolyophilous fungi (on burnt areas and substrates), resincillous fungi (on resin), rumen fungi (in anaerobic rumen environment), sewage fungi (polluted water), thermophilic fungi (at or above 45 °C), water moulds (in water), and xerotolerant fungi (at < 0.85 aw) (see Maheshwari 2005).

Given the current importance placed on ecotourism and the preservation of unique southern African flora and fauna, it is clearly timely that some thought, financial resources and research be focused on preserving the basal links of the ecosystem, which are the fungi. Clearly, South Africa’s undescribed fungi represent a vast biological resource which has yet to be collected, cultured and studied. Undoubtedly the fungi of southern Africa contain numerous beneficial biological properties and other attributes that could be used to greatly improve the quality of life for all future generations of humanity.

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