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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 *Campuloclinium 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 cataloguing 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 desert 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 still 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 Middelburg, Aberdeen and the Baviaanskloof 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 & Burtt 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 main centres of diversity of mosses in southern Africa.

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.

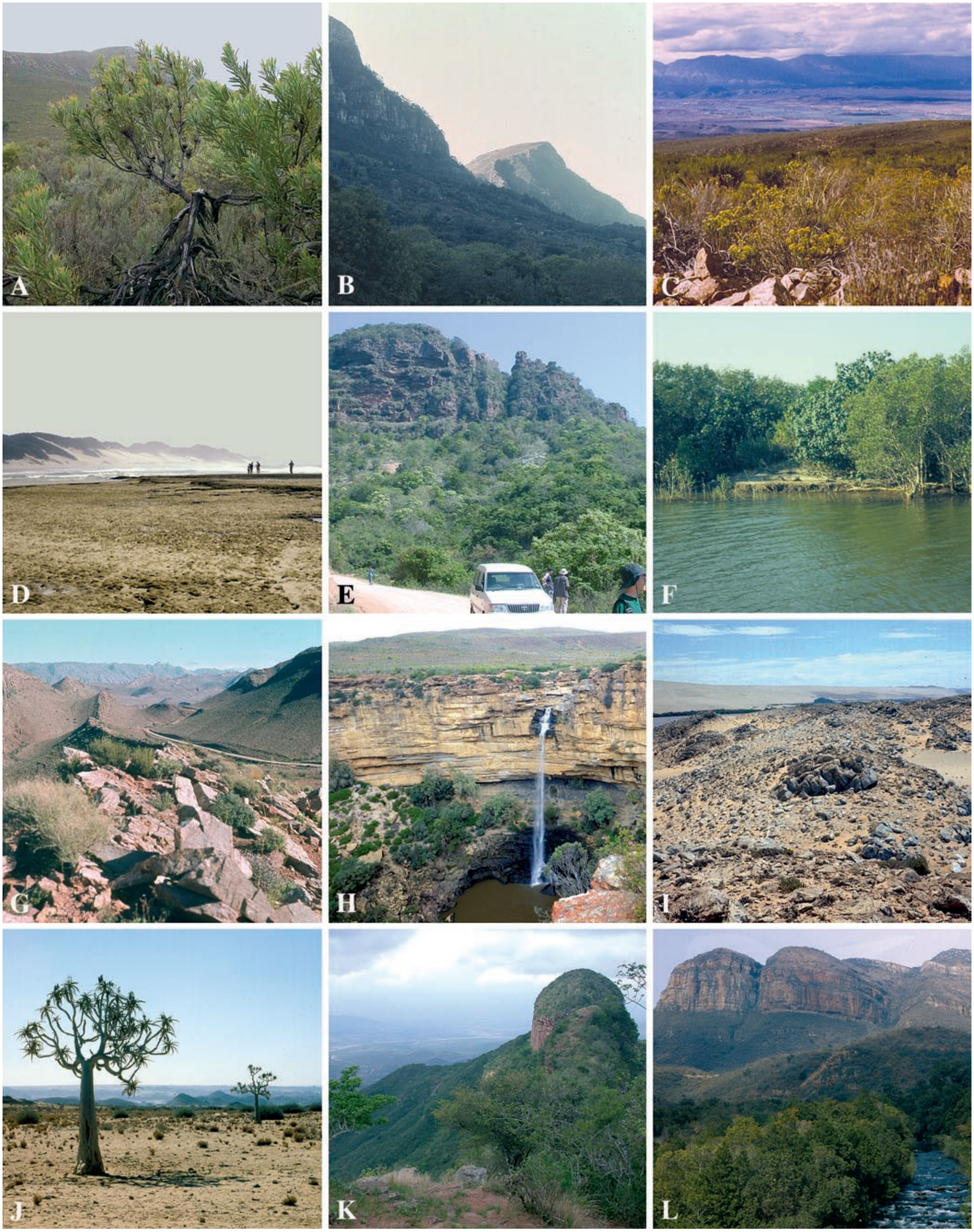

Fig. 1. Unique South African flora. A–C. Cape Floristic Region. D. Beach vegetation. E. Coastal forest. F. Mangrove vegetation. G. Ceres Karoo. H–J. Succulent Karoo. K. Bushveld and grassland. L. Wolkberg centre. All photographs by H. Glen, except A by P.W. Crous.

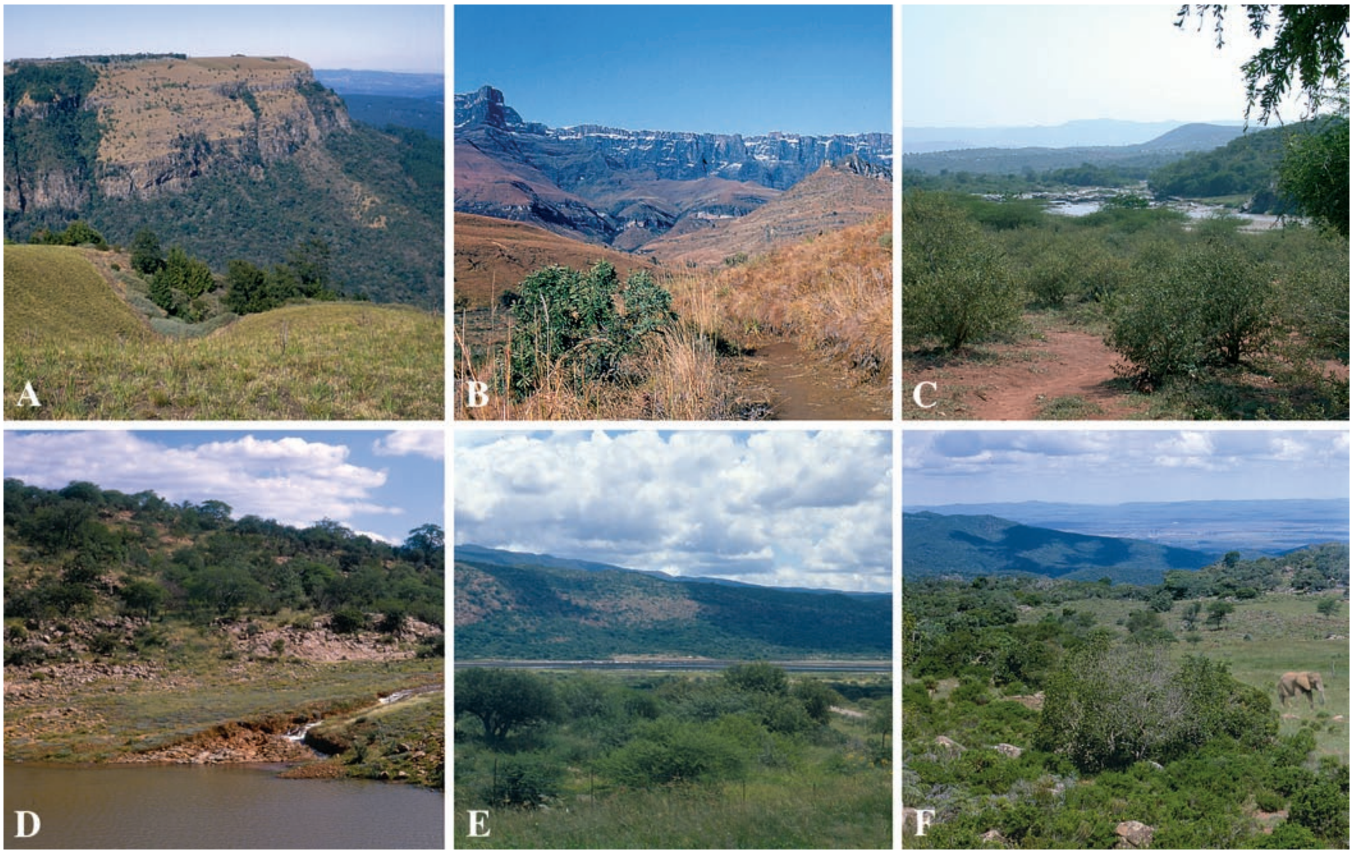

Fig. 2. Unique South African flora (continued). A. Wolkberg centre. B. Montane grassland. C. Degraded bushveld. D–F. Soutpansberg centre. Photographs by H. Glen.

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 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 Afirica 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

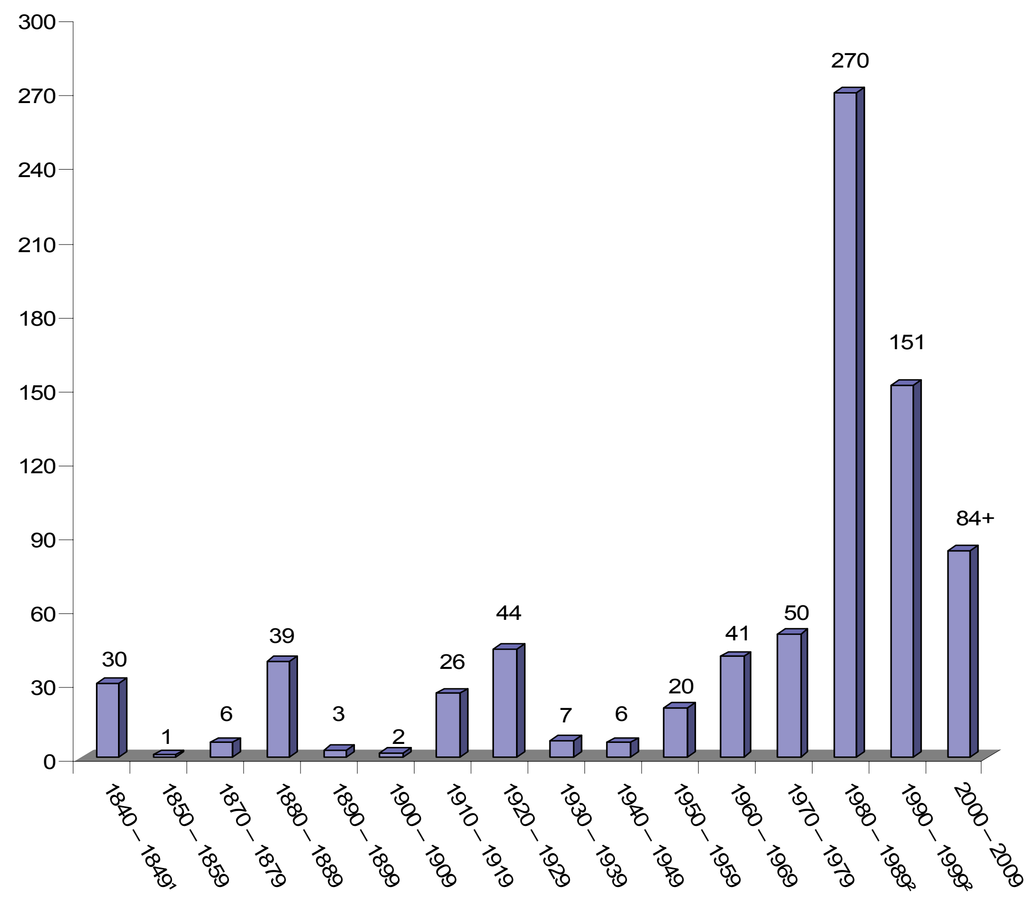

Fig. 3. Approximate number of species described from South Africa[1].

[1]Data derived from Index Fungorum <www.indexfungorum.org/Names/Names.asp>.
[2]The 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/fungaldatabases/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 (*Erysiphaceae*) (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 rhizophila* 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 aetiology 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 *Phaeoacremonium* 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 Warmelo 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 *Phaeophleospora* 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* (Pavlic *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 *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 *Cryphonectria* (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 *Eucalyptus* stem pathogen *Cryphonectria cubensis* (Bruner) Hodges in South Africa (Wingfield *et al*. 1989). The various studies, strongly supported by DNA sequence comparisons, have shown that *Cryphonectria* 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 *Chrysoporthe* Gryzenh. & M.J. Wingf. (Gryzenhout *et al.* 2004), *Microthia* Gryzenh. & M.J. Wingf., *Holocryphia* Gryzenh. & M.J. Wingf. (Gryzenhout *et al*. 2006), *Rostraureum* Gryzenh. & M.J. Wingf. (Gryzenhout *et al.* 2005a) and *Amphilogia* Gryzenh., Glen & M.J. Wingf. (Gryzenhout *et al.* 2005b). New species and genera have also been discovered that are closely related to *Cryphonectria*, such as *Celoporthe dispersa* Nakab., Gryzenh., J. Roux and M. J. Wingf. (Nakabonge *et al*. 2006 – this volume).

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 *Fusarium* Link (Marasas *et al*. 1988), *Penicillium* Link (Schutte 1992), *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 *Cercospora* Fresen. and similar fungi (Crous & Braun 1995), revision of the genus *Cylindrocladium* Morgan and related genera (Crous & Wingfield 1993, 1994, Crous 2002), and differentiation of species of *Bipolaris* Shoemaker*, Exserohilum* K.J. Leonard & Suggs and *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), *Cenchrus ciliaris* pastures (Bezuidenhout 1977), natural Karoo pastures (Roux 1985), as well as toxigenic representatives of *Fusarium* (Kellerman *et al*. 1972, Marasas *et al*. 1976) and *Pithomyces* Berk. & Broome (Marasas & Schumann 1972, Kellerman *et al*. 1980), and various synnematous and other hyphomycetes (Rong & Botha 1993, Roux *et al*. 1995, Jacobs *et al*. 2001). Other genera that received attention include *Graphium* Corda (Jacobs *et al.* 2003b), *Leptographium* Lagerb. & Melin (Wingfield & Marasas 1980, 1983, Wingfield 1985, Zhou *et al*. 2001), *Cladosporium* Link (Braun *et al*. 2003, Surridge *et al*. 2003), *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 *Proteaceae* and *Restionaceae* in the fynbos (Wingfield *et al*. 1988, Mel'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 *Fusarium*, including soil surveys (Rheeder & Marasas 1998), and the description of numerous new species such as *Fusarium andiyazi* Marasas, Rheeder, Lampr., K.A. Zeller & J.F. Leslie (Marasas *et al*. 2001), and *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 *Cercosporella* Sacc., then *Pseudocercosporella* Deighton, and *Ramulispora* Miura (Robbertse *et al*. 1995). Crous *et al*. (2003) erected the genus *Helgardia* Crous & W. Gams to accommodate these cercosporoid anamorphs, while their discomycete teleomorphs were placed in the genus *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 *Nalanthamala* Subram.

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

Species of *Cylindrocladium* Morgan (teleomorph: *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 teleomorphs of *Cylindrocladiella* Boesew. in *Nectricladiella* Crous & C.L. Schoch. In subsequent years Schoch & Crous (1999) reported *Cylindrocladium spathiphylli* Schoult., El-Gholl & Alfieri as causing Cylindrocladium root and petiole rot of *Spathiphyllum*, while Schoch *et al*. (1999) resolved the *Cylindrocladium candelabrum* Viégas species complex, describing the common soil-inhabiting species in South Africa as *C. pauciramosum* C.L. Schoch & Crous. In a recent monograph of *Cylindrocladium* and allied genera, Crous (2002) reported six *Cylindrocladium* species and five *Cylindrocladiella* species from South Africa.

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 *Colletotrichum* Corda*, Phyllosticta* Pers.

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

Paraconiothyrium minitans (W.A. Campb.) Verkley was investigated as an antagonist of the devastating pathogen, *Sclerotinia sclerotiorum* (Lib.) de Bary (Phillips 1985). Possibly the most notorious coelomycetes in South Africa are *Phyllosticta citricarpa* (McAlpine) Aa, the cause of black spot of oranges (Meyer *et al*. 2001), 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). Coelomycetous 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* Massee, *Clathrus* P. Micheli ex L., *Hymenagaricus* Heinem., *Lepiota* (Pers.) Gray, *Macrolepiota* Singer, *Leucoagaricus* Locq. 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 *Basidiomycota* 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 teleomorphs (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 teleomorphs. 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 presently recorded from southern Africa (A. Wood, unpubl. data). This tally will increase, as several more new species and records await publication. Of the countries included, southern Angola, Botswana, Mozambique, Namibia and Swaziland have few species recorded, and Lesotho has none. Only South Africa and Zimbabwe are relatively well explored mycologically, though little or no collecting has been done in large areas of even these two countries. A total of 20 new species have been described from the Western and Northern Cape Provinces of South Africa, and Namibia, in just the last 5 years (Wood 2002, Mennicken *et al.* 2003, Mennicken & Oberwinkler 2004, Mennicken *et al.* 2005a, b, Wood & Crous 2005, Wood & Scholler 2005), demonstrating that many new species await discovery in the subregion where there has been little or no collecting in the past. However, the number of species known to occur is probably not a gross underestimation of the actual total present, as with the study of fresh specimens it is probable that a number of species will be reduced to synonyms, and many anamorphic species will be linked to their teleomorphs.

Hennen & McCain (1993) suggested that the number of rust species in any area would be at least 5 % of the number of vascular plants. In South Africa and Zimbabwe the figures are only 1.7 and 3.2 %, respectively (Table 1). As stated above, the number of species is not considered likely to rise considerably. Why then are there relatively few rust species recorded from the subcontinent in comparison to other countries (Table 1)? 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. bolusii* Massee, *U. ixiae* (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

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)

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 *Teloschistes* 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 exsciccate, "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 *Karoowia* 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 Uppsala 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 *Karoowia 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.*, Lichenoconium* 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.)

Hale species in the country (D.L. Hawksworth, pers. obs.), and an undescribed *Polycoccum* on *Karoowia adhaerens* (Nyl.) Hale (Váczi & 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 *Pythuim* Pringsheim species date from 1931 to 2004. Twenty species of *Pythium* 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 Wager (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. porri* 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 & Coetzer (1996) and *Pythium prolatum* 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. irregulare* Buisman*, 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 Greuning, Sinclair and later during a survey of the fungi associated with *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). Viljoen *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. mearnsii*, 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 km^2, 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.

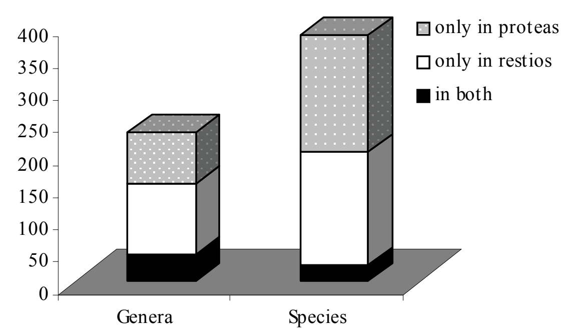

Fig. 4. Numbers of fungal taxa associated with two plant groups: *Proteaceae* (proteas) and *Restionaceae* (restios).

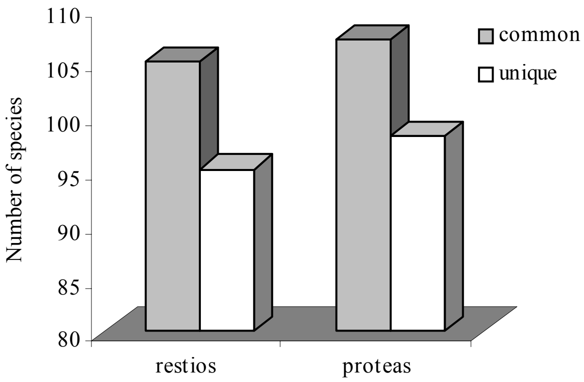

Fig. 5. Numbers of fungal species that are unique to each plant group (unique) and are found on other host plants (common).

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 (Zwölfer 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 arthopods 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, Kirisits 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 (*Macrotermitinae*) in Southern Africa (Uys 2002). These studies on ophiostomatoid fungi associated with beetles, *Protea* spp. (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 Schrank 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 fungi, 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 ration 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 (Kohlmeyer & 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 synonymies 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 hyphomycetes 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 hyphomycetes 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 foliicolous 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), bryophilous 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), mycorrhizal fungi (symbiotic with plant roots), mycoparasites (on other fungi), nematophagous fungi (parasitic on nematodes), osmotolerant fungi (growing at high osmotic pressure), psychrophilic fungi (at < 10 °C), pyroxylophilous fungi (on burnt areas and substrates), resinicolous 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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