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Above: (L) Silver Wattle *Acacia dealbata*; (R) *Clematis aristata*.
Below: Rough Tree Fern *Cyathea australis*.
Photos by Maria Gibson.

An overview of the fungi of Melbourne

Tom W May

Royal Botanic Gardens Melbourne, Private Bag 2000, South Yarra, Victoria 3141

Abstract
Numerous fungi are found in greater Melbourne due to the variety of substrates available in parks and gardens and in remnant native vegetation. Specimen and sight record data on the 866 fungi known from Melbourne are summarised. In the National Herbarium of Victoria there are 2501 collections of fungi from greater Melbourne representing 549 non-lichenised and 269 lichenised species. In the Fungimap database, there are 2664 records of 155 species, including 48 species not represented in the National Herbarium. Examples of common species are tabulated. Fungi associated with particular substrates or habitats are summarised, including those on dead wood and litter and in lawns as well as ectomycorrhizal partners of exotic and native trees. Remnant native vegetation harbours considerable fungal diversity. Important questions remain to be answered about factors affecting the occurrence of fungi and the potential effects of climate change. New tools from the Atlas of Living Australia will assist in compiling and analysing data, and molecular data has the potential to expedite species identification. Melbourne is an excellent locale to study fungi due to its concentration of naturalists in combination with a variety of habitats suitable for fungi. (*The Victorian Naturalist* **128** (5) 2011, 183–197)

Keywords: Ectomycorrhizal fungi; saprotrophic fungi; biodiversity; inventory; urban ecology

Introduction

The *Handbook of Melbourne*, compiled as a guide to attendees at the meeting of the Australasian Association for the Advancement of Science held in Melbourne in 1900, included chapters on topics such as geology and climate and on various animal groups. There was also a chapter on botany, but this did not mention fungi. Until the mid 20th century fungi were usually treated as lower plants, but are now considered to belong to a separate kingdom of the living world with their own unique structure and biology.

Knowledge of Australian fungi did lag behind that of other groups such as flowering plants, birds and mammals (May and Pascoe 1996). However, by the end of the 19th century a *Handbook to Australian Fungi* had been compiled by Mordeccai Cooke, an English Mycologist. Cooke never came to Australia, but based his descriptions of species on the numerous specimens sent to European herbaria by collectors from across Australia, including many from Victoria. Around the same time, in 1890, Daniel McAlpine had been appointed to the post of Consulting Vegetable Pathologist with the Victorian Department of Agriculture, based in Melbourne (May and Pascoe 1996). The 'father of Australian plant pathology', McAlpine was not only a fine plant pathologist but a prolific writer on fungi. His publications included comprehensive monographs on the rust- and smut-fungi, including species on both crop plants and native hosts. Admittedly, work on the larger fungi such as mushrooms and coral fungi did not start in Australia until a few decades into the 20th century, commencing with the efforts of mycologists such as John Cleland (May 1990).

Whatever the reasons for the omission of fungi from the 1900 *Handbook of Melbourne*, the inclusion of Fungi in the 2010 FNCV Biodiversity Symposium provided an opportunity to survey the fungi of Melbourne in terms of past and current knowledge and research, and in regard to future prospects for improving information on, and understanding of, fungi in Melbourne.

Melbourne as habitat for fungi

While urban areas are not so favourable for some groups of native biota, such as mammals, Melbourne is a rich habitat for fungi because there is plenty of vegetation, both in private and public gardens and also in remnant and regenerated bushland. All parts of plants, at all stages, living and dead, are food for fungi. The variety of species of plants, both in cultivation and in the bush, and the different forms of dead plant material (leaves, logs, stumps, mulch etc.) provide numerous substrates for different species of fungi. Even an average suburban backyard with lawn, garden beds and trees, as well as piles of tree clippings and compost, has numerous substrates suitable for fungi.

Fungal dispersal is by minute, mostly wind-dispersed spores, and thus fungi can rapidly colonise newly available substrates; whether a recently created earth bank next to a freeway (a favourite site for *Coprinus comatus*), a freshly mulched garden bed or a newly planted seedling.

Fungi are most obvious to people firstly as pathogens of garden plants, particularly noticeable on vegetables and fruit trees, but also occurring on all exotic and native plants. Secondly, people are aware of the unwanted effects of wood-rotting fungi that can weaken housing timbers, especially when not protected from water. Thirdly, fungi intersect with the human inhabitants of the city when consumed as food (Field Mushroom *Agaricus campestris*) or causing poisoning such as from ingestions of Yellow Stainer *Agaricus xanthodermus* or Death Cap *Amanita phalloides* (Fig. 1). However, the important ecological roles of fungi in nutrient recycling and as mutualistic partners of most green plants are largely overlooked, although these roles are carried out under our noses in every park and garden.

Most fleshy fungi, such as mushrooms, produce fruit-bodies for only a couple of weeks, usually in autumn after suitable rain. However, the vegetative mycelium is often persistent and fruit-bodies can appear in the same spot from one year to the next, but not always every year. Urban fungi have not received much attention in the scientific literature. A recent review by Newbound *et al.* (2010b: p. 143) concluded that 'it is conceivable that urbanisation is causing the loss of fungi before they are recorded and their value understood'. Newbound *et al.* (2010b) emphasised the important ecological roles of fungi, including direct effects as partners in mutualisms such as mycorrhizas, but also as food for animals, and noted that fungi also contribute to maintaining good soil structure. These authors also highlight the potential threats to fungi through altered soil nutrient status, especially elevated levels of nitrogen and phosphorus, and negative effects of soil acidity and heavy metal pollution.

Fig. 1. Death Cap *Amanita phalloides* under Oaks on the Oak Lawn, Royal Botanic Gardens Melbourne.

Data sources on Melbourne fungi

Melbourne is interpreted in a broad sense ('greater Melbourne') with an area of more than 8000 km^2, including both highly urbanised inner suburban areas and outer suburban areas often with large areas of bushland, but not extending to towns separated by predominantly rural areas, such as Healesville and Warburton. Apart from a short entry on Fungi in the *Encyclopedia of Melbourne* (May 2005a) there is no compilation or checklist of the fungi of Melbourne.

From the earliest days of the Field Naturalists Club of Victoria, fungal forays were held, sometimes in areas within or close to Melbourne such as Lilydale (May 2005b). From the time that James ('Jim') Willis was involved with the Club, some foray lists were published, such as those for visits to Humphries Hill, Frankston (McLennan and Willis 1937) and Sherbrooke Forest (Willis 1968). In addition, there are likely to be unpublished fungal foray lists among the Willis papers held in the archives of the Royal Botanic Gardens Melbourne. In the last decade, the Fungi Group of the FNCV has carried out around 10 fungal forays each year, mainly in areas outside of (but near to) Melbourne. Full lists are compiled for each foray and most of these lists have been submitted to the Fungimap database. A fungal survey of Wattle Park was carried out by the FNCV in the mid 1990s, yielding numerous collections (May 2005b).

From the inception of the Fungimap fungi mapping scheme (see box 1) in the mid 1990s, numerous sight records have been submitted from Melbourne. Fungimap records are mainly of 115 target species, but there are also records of other species, especially among the FNCV Fungi Group forays.

> **FUNGIMAP**
> Fungimap Inc. is a national organisation dedicated to improving knowledge and conservation of native fungi. The mapping scheme undertaken by Fungimap focuses on readily recognisable target species of macrofungi. There are currently 115 target species, most of which are covered by *Fungi Down Under* (Grey and Grey 2005). Records are welcome from members and non-members. For instructions to recorders, training opportunities, membership and issues of the *Fungimap Newsletter* see: http://www.rbg.vic.gov.au/fungimap

Collections of fungi from Melbourne are held mainly in the National Herbarium of Victoria (MEL). During the 19th century Ferdinand von Mueller encouraged collecting of fungi from a wide network of collectors (May and Pascoe 1996), and in the 20th century, current and past herbarium staff, such as Jim Willis, have continued to collect fungi, have encouraged others to do so, and have ensured that there is a home for significant fungal herbaria such as that formerly held in the CSIRO Division of Forest Products, assembled by Neville Walters. Most fungi held in MEL are databased and have geocode information available. The most significant other set of macrofungal specimens from Melbourne is held in the Herbarium of Royal Botanic Gardens Kew (K), sent mainly in the 19th century. However, these specimens are not yet databased.

Method of compiling a list of the fungi of Melbourne

To gain a list of fungi specifically from Melbourne requires cross matching of the area within the boundary of greater Melbourne (which is irregular) with specimen and sight record data. This is not readily achievable within the current structure of herbarium and sight record databases, and therefore as an initial effort at compiling a list of fungi from Melbourne, both the MEL holdings and the Fungimap record database were queried for all Fungi, firstly from locations that had the word 'Melbourne' and were from Victoria, and secondly from locations within the rectangle defined by latitude 37°40' to 38°00'S and longitude 144°50' to 145°20'E. The rectangle sits within greater Melbourne, roughly bounded by Altona in the west, Hurstbridge in the north, Lilydale in the east and Dandenong in the south, and is about 2000 km^2 (inclusive of some of Port Philip Bay). However, this rectangle does not include substantial portions of greater Melbourne, particularly to the north and east and along the Mornington Peninsula. The records analysed should be regarded as a sample that will represent a reasonable proportion of the specimens and records in the MEL and Fungimap databases that are from greater Melbourne. This allows detection of common species and trends.

For each of the MEL specimens and Fungimap records, results of the two queries were combined, duplicate records removed and older names updated. Some records were also removed that had the word 'Melbourne' in the locality, but in contexts such as '120 km W. Melbourne'. Some of the herbarium records for MEL had been duplicated in the Fungimap database because at the outset of Fungimap, before Australia's Virtual Herbarium was in operation, they had been added here. Therefore, herbarium records for MEL were removed from the Fungimap data, but not the small number of records from the National Collection of Fungi, Knoxfield Herbarium (VPRI), the State Herbarium of South Australia (AD) and the Australian National Herbarium (CANB), almost all of which are for pre-1990 collections.

The frequency of occurrence of each species among the MEL holdings and Fungimap records was calculated separately. One hundred and six species, mostly represented by more than one collection and/or record, are listed in Tables 1-6. In the tables, species are grouped under readily recognisable groups of convenience, such as 'mushrooms', as used in field guides such as Fuhrer (2005) and Grey and Grey (2005), rather than by taxonomic groups such as families. Most species listed in the tables are represented by voucher specimens held in the National Herbarium of Victoria that have been collected from the greater Melbourne area.

Names used follow the draft master list of Australian fungi, currently in preparation for the Atlas of Living Australia, which for most species corresponds to the names used in the *Interactive Catalogue of Australian Fungi* (http://www.rbg.vic.gov.au/dbpages/cat/index.php/fungicatalogue). Many MEL specimens and almost all Fungimap records already had up-to-date names, but some older synonyms had to be updated.

Identification of species was that provided on herbarium specimens and for sight records. Therefore, it is quite likely that some identifications need to be revised. In particular, some names are used in a broad sense. An example is the *Pluteus cervinus* group, where closer examination, particularly of microscopic characters, may well show that the local collections belong to other species of similar appearance.

The fungi of Melbourne

There is a total of 2501 collections of fungi from the Melbourne area in the National Herbarium of Victoria. Some 2444 collections were from the defined rectangle and a further 57 collections were from outside of this rectangle, but had the word 'Melbourne' as part of their locality information.

Fungi collections from Melbourne have been made by 276 different collectors, but more than half (63%) the collections were contributed by just 15 collectors, who each contributed more than 50 collections. These included Charles French Jnr, James Minchin and Felix Reader, whose collections date from the latter decades of the 19th century, no doubt encouraged by Mueller. In the 20th century Neville Walters made numerous collections of wood-decaying fungi, originally housed in the herbarium of the CSIRO Division of Forest Products. A significant collection of fungi, including many from Melbourne, was donated to MEL by George Crichton. Jim Willis collected fungi between 1933 and 1997, and in the period since 1980, fungi from Melbourne have been lodged at MEL by Bruce Fuhrer, John Eichler, Teresa Lebel, Tom May, Nigel Sinnott and the Field Naturalists Club of Victoria.

Significant collections of lichens from the Melbourne area were made by Richard Bastow and Francis Wilson at the end of the 19th century and by Val Stajsic in recent decades. Six of the major collectors have been, or are, staff members of the Herbarium (French, Minchin, Willis, May, Lebel and Stajsic).

Graphs of the number of collections per decade (Figs 2 and 3) reflect the activities of these major collectors, with a peak for lichens in the decades 1890s and 1900s, and for fungi in the 1880s and again in the 1950-1970s (many from Neville Walters and George Crichton) and then increased collecting activity in the last couple of decades.

Most of the fungi collections in MEL from Melbourne are macrofungi, but there are a few collections of microfungi, such as rust-fungi on native host plants. The fungi collections in MEL are a mix of cosmopolitan species, exotic species that have been introduced (often with exotic trees) and native species, specifically associated with native hosts. Individual species belonging to different groups of fungi are discussed in more detail in the following sections, and in the Tables.

Of the 2501 collections, 1907 (76%) are identified to a total of 818 species (549 non-lichenised and 269 lichenised). The remaining collections are either identified to genus or only to higher levels such as family. Among the lichenised fungi the percentage of collections identified to species is 87% (of 735 collections), in comparison to 72% (of 1766 collections) for the other fungi. This reflects the greater knowledge and availability of keys for macrolichens.

Among the 549 identified species of non-lichenised fungi, the most commonly collected are: *Fuscoporia contigua* (mostly from housing timber such as weatherboards), *Serpula lacrimans* (dry rot on housing timber, particularly floorboards and joists), *Schizophyllum commune*, *Fomitopsis lilacinogilva*, *Stereum hirsutum*, *Hypholoma fasciculare* and *Leratiomyces ceres* (most often recorded as *Stropharia aurantiaca*). Except for the *Hypholoma* and the *Leratiomyces*, all these species have persistent fruit-bodies. However, fungi with fleshy and short-lived fruit-bodies, such as mushrooms and coral fungi, are well represented among the other identified species.

There are 2664 Fungimap records from Melbourne contributed by 130 recorders, with 10 recorders contributing 71% of the records. People contributing more than 100 records are Robert Bender, Cecily Falkingham, Pat and Ed Grey, Dorothy Mahler, Tom May, John Eichler, Ivan Margitta, Nigel Sinnott and Virgil Hubregtse. The first records arrived at Fungimap in 1995, and there is a peak of records from Melbourne in 1999 (Fig. 4) and a decrease in recent years. The most frequently recorded of the 155 species in the Fungimap database are: *Agaricus xanthodermus* (431 records), *Gymnopilus junonius* (usually as *G. pampeanus*) (289), *Oudemansiella radicata* (now known to be an aggregate, including species such as *Xerula gigaspora*) (209), *Amanita muscaria* (195), *Coprinus comatus* (140), *Amanita xanthocephala* (137), *Volvariella gloiocephala* (as *V. speciosa*) (109), *Bolbitius vitellinus* (104) and *Mycena viscidocruenta* (100). Among the Fungimap records from Melbourne are 48 species which are

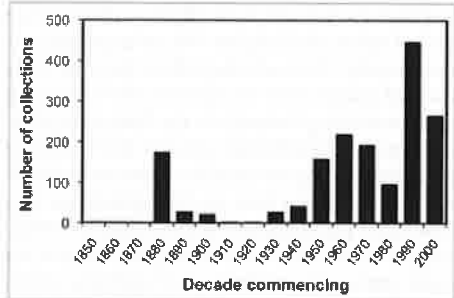

Fig. 2. Number of collections of fungi (excluding lichens) from Melbourne in the National Herbarium of Victoria, by decade of collection date.

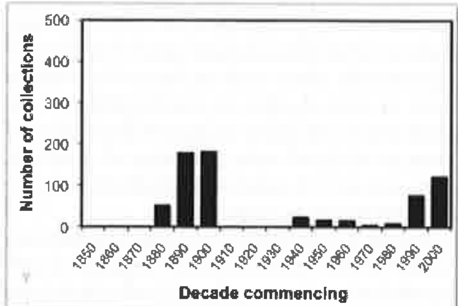

Fig. 3. Number of collections of lichenised fungi (lichens) from Melbourne in the National Herbarium of Victoria, by decade of collection date.

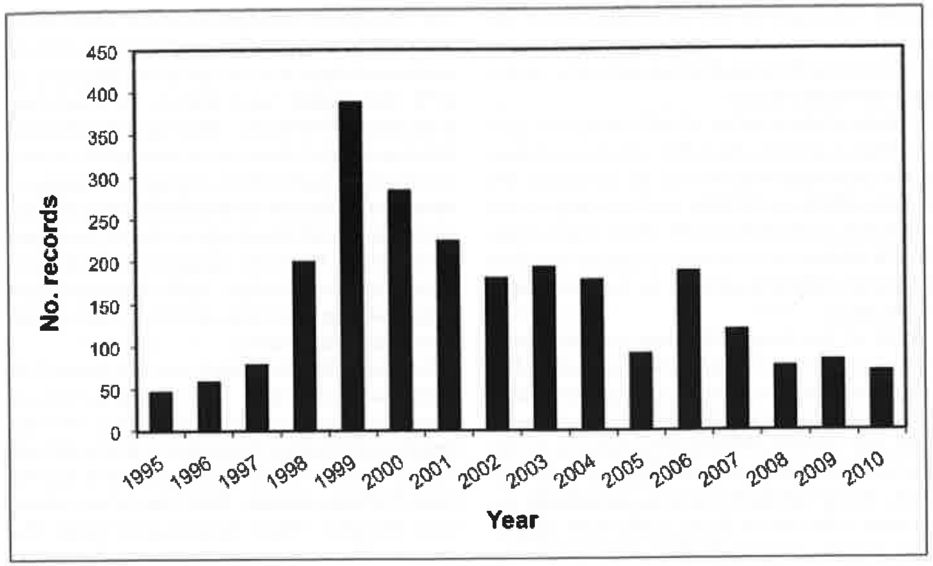

Fig. 4. Number of Fungimap records for Melbourne by year of observation.

not represented by specimens in the National Herbarium of Victoria from Melbourne, including distinctive species such as *Cortinarius australiensis* and *C. rotundisporus*.

Comparative data are not available for other Australian cities. However, for King's Park in central Perth, which contains more than 250 ha of bushland, Bougher (2010) records 285 species of fungi, of which 140 are supported by voucher specimens.

Lichenised fungi

Lichenised fungi (commonly known as lichens) are fungi that grow in association with a photobiont (either green algae or cyanobacteria). Lichenisation allows fungi to grow in otherwise inhospitable sites, such as on rocks. Lichens have ecological roles in weathering and are particularly important as part of the biotic soil crust in arid and semi-arid areas of Australia. They are also of value as bioindicators due to their sensitivity to air pollution.

Among the 269 species of lichenised fungi recorded for Melbourne, the most commonly collected (each with more than 10 collections) are, in order of number of collections: *Flavoparmelia rutidota, Hyperphyscia adglutinata, Punctelia subrudecta, Ramalina glaucescens, Pertusaria pertractata* (as *P. gibberosa*), *Xanthoria coomae, Tephromela atra* and *Cladia aggregata*. Lichens are present in remnant bushland, parks and gardens, and many houses harbour lichens on roofing tiles or solar hot water panels. Prominent lichens in Melbourne include *Xanthoparmelia scabrosa* (on asphalt and roofing tiles) and *Flavoparmelia rutidota* (on fallen timber in remnant bushland and also on fences and planted trees).

Pathogenic fungi - mostly microfungi

Melbourne is likely to be home to many hundreds, if not thousands, of species of pathogenic fungi. Most of these fungi are microscopic, visible only through their effects on hosts, such as leaf spots and blights. Microfungi are predominantly Ascomycota, often forming only asexual spores, but, in contrast, the rust-fungi and smut-fungi belong to the Basidiomycota. Cunnington (2003) lists around 400 species of pathogenic fungi on introduced plants in Victoria, occurring not only on crop plants but also cultivated garden plants, vegetables and weeds. Earlier lists, such as Washington (1983) for plant pathogens on fruit and vegetable crops, provide specific localities for the first record of each disease on each host, many of which are within greater Melbourne.

As one example of the many different groups of microfungi, rust-fungi form small yellow or brown pustules on leaves and stems. Commonly encountered rust-fungi on weeds in suburban gardens include *Puccinia lagenophorae* (on *Bellis*) and *P. malvacearum* (on *Malva*).

There will also be numerous native pathogenic microfungi on the variety of native plants that are utilised in horticulture. Galls formed by the native rust *Uromycladium* are prominent on many *Acacia* species, both when cultivated and in bushland remnants.

Amongst the larger fungi, the most significant pathogen is the Australian Honey Fungus *Armillaria luteobubalina*. This native mushroom attacks not only native plants but also a range of exotic trees and shrubs, including citrus. Species of *Ganoderma* such as *Ganoderma australe* (commonly misidentified as *G. applanatum*), are also common on trees in parks and gardens.

Fungi on dead wood and litter

Stumps and larger dead wood, including dead standing trees, are home to various bracket fungi and mushrooms that decompose the wood (Table 1). These fungi may be entirely saprotrophic, feeding only on dead wood, or have varying degrees of pathogenicity, attacking also the living sap wood of live trees (Marks *et al.* 1982). However, many fungi arising from living trees are not pathogens, but are wood decay fungi feeding on the substantial column of dead heart wood that is present in a living tree. Thus, *Laetiporus portentosus* causes brown cubical rot of living trees such as River Red Gum *Eucalyptus camaldulensis*.

Earthstars such as *Geastrum pectinatum* and *G. indicum* are common in gardens but easy to overlook due to their drab, grey or brown coloration. There are also numerous less obvious fungi that grow on small woody debris and leaf litter, particularly among the 'paint fungi' that form resupinate fruit-bodies closely adhering to the substrate. When dead branches are left in a dense pile for a couple of years, there will be a variety of fungi in genera such as *Hyphodontia*, as long as there is some moisture present. There is a range of macroscopic structure among the 'paint fungi' with variation in colour and in the fine structure of the surface (pored, spined,

Table 1. Some fungi on stumps, dead roots, logs and dead standing wood in Melbourne parks and gardens. Some also occur in native bushland (e.g. *Omphalotus nidiformis*).

Mushrooms
Agrocybe cylindrica (on Poplar *Populus* and Elm *Ulmus*)
Coprinellus disseminatus
Flammulina velutipes
Gymnopilus junonius (=*G. pampeanus*)
Hypholoma fasciculare
Omphalotus nidiformis
Schizophyllum commune

Polypores
Abortiporus biennis
Amauroderma rude (on wattles *Acacia*)
Ganoderma australe
Phaeolus schweinitzii (on conifers)
Trametes hirsuta
Trametes versicolor

Stereoid fungi
Chondrostereum purpureum

labyrinthine or quite smooth) but identification usually requires examination of microscopic features.

Mulch consisting of large pieces of wood (wood chip mulch) is very commonly used in parks and gardens (and even in areas without plantings, such as some roundabouts) to suppress weeds, reduce compaction and retain moisture. Wood chip mulch is an excellent substrate for saprotrophic fungi, including some mushrooms, stinkhorns, birds nest fungi and slime moulds (Table 2). The mycelium of the fungus grows on and between the wood chips and, where wood chips are laid thickly, the water retained in the mulch also assists fungal growth. In the first year or two after the mulch is laid, there can be spectacular fruitings of fungi, such as *Coprinellus micaceus* (Fig. 9). Over time, fewer fruit-bodies are formed as the nutrients in the mulch are used by the fungi.

Saprotrophic fungi on wood, litter and mulch are a mix of exotic species associated with specific hosts (such as *Phaeolus schweinitzii* on pine), native species, and cosmopolitan species. Native species are often found on native hosts: *Mycena viscidocruenta* has a strong preference for eucalypt litter; *Mycena nargan* is often found on eucalypt sleepers; and *M. clarkeana* occurs on dead *Banksia* or at the base of *Melaleuca* planted as street trees (front

Table 2. Some fungi observed in garden beds in Melbourne parks and gardens, particularly on or amongst wood-chip mulch.

Mushrooms
Agrocybe praecox group
Chlorophyllum brunneum [also in garden beds without wood-chips, preferring rather dry sites, such as beneath *Cupressus*]
Coprinellus micaceus
Coprinopsis atramentaria
Gymnopilus dilepis
Lacrymaria asperospora [also in lawns and gravel drives]
Leratiomyces ceres (=*Stropharia aurantiaca*)
Leucoagaricus leucothites [more common in garden beds amongst litter than strictly on woodchip mulch]
Parasola plicatilis
Pluteus cervinus group
Psilocybe crobula
Psilocybe subaeruginosa
Volvariella gloiocephala (=*V. speciosa*)

Birds Nest Fungi
Cyathus olla
Sphaerobolus stellatus

Stinkhorns
Anthurus archeri
Aseroe rubra
Ileodictyon cibarium and *Ileodictyon gracile*

Slime moulds
Fuligo septica

cover). The lack of early collections makes determination of the biostatus (as native or exotic) difficult, particularly for widespread species that favour disturbed ground, such as *Coprinus comatus* (Fig. 5). One obviously introduced exotic fungus is *Favolaschia calocera*, whose bright orange, massed fruit-bodies were first sighted in 2005 in Wilson Reserve in Ivanhoe.

Fungi in lawns

Fungi growing in lawns well away from trees and shrubs are mostly saprotrophs that break down dead grass or organic matter in the upper layer of the soil (Table 3). Most are mushrooms that are short-lived and relatively small (such as *Bolbitius vitellinus*), although massed fruitings of *Agaricus xanthodermus* and other species of *Agaricus* and *Lepista* may occur briefly in autumn. Some species, such as *Panaeolina foenisecii*, also produce fruit-bodies in warmer months, if there is suitable rain.

At least a dozen species of *Agaricus* occur in Melbourne, and in some years can be very numerous, not only in lawns, but also on bare ground and amongst litter under planted *Acacia* and *Eucalyptus*. Species include: *Agaricus bitorquis* (particularly in compacted soil or pushing up through asphalt such as in car parks or paths), *A. campestris* (the true Field Mushroom), *A. arvensis* (Horse Mushroom) and *A. augustus*.

Many Melbournians expect to collect the Field Mushroom *Agaricus campestris* in autumn, often due to childhood experiences of collecting mushrooms in farm paddocks. The mushroom most common in paddocks seems to be the large Horse Mushroom *Agaricus arvensis*. Unfortunately, in urban areas the toxic Yellow Stainer *Agaricus xanthodermus* is very prevalent, and other edible species of *Agaricus*, especially *A. campestris*, are comparatively less common. This is possibly due to different species having preferences for different levels of soil nutrients, such as nitrogen, and the nutrient levels having

Fig 5. *Coprinus comatus*, a common saprotrophic mushroom in lawns and on disturbed ground.

Table 3. Some fungi growing in lawns in Melbourne parks and gardens.

Mushrooms
Agaricus arvensis
Agaricus xanthodermus
Bolbitius vitellinus
Coprinus comatus
Lepista luscina
Marasmius oreades
Panaeolina foenisecii
Psathyrella candolleana group

Puffballs
Vascellum pratense

changed over time, especially because horses are no longer used for transport.

Lawn fungi observed in Melbourne are all cosmopolitan, and are likely to have been introduced to Australia. The possibility that some occur naturally in indigenous grassland has not been investigated. Fungi of such grasslands, which are highly threatened and much reduced in area, are very poorly known.

Saprotrophic fungi in lawns (such as *Marasmius oreades*) often form fairy rings (Fig. 6), where there is a ring of fruit bodies associated with an enhanced growth of grass around the ring, and sometimes inside as well. The ring is formed by regular outward growth from an initial small mycelium that proceeds at an even rate in all directions from one year to the next as the mycelium exhausts nutrients in the interior of the ring.

Ectomycorrhizal fungi associated with shrubs and trees

Ectomycorrhizal fungi form a mutually beneficial relationship with shrubs and trees from many plant families, especially in the Myrtaceae and Fagaceae. The mycelium is intimately associated with the fine roots of the plant host, and there is an exchange of nutrients. Fruit-bodies of ectomycorrhizal fungi usually occur directly under or very near to the canopy of the host tree. Some ectomycorrhizal fungi have broad host ranges, but many form associations only with particular families or genera of plants. Some of the more common exotic ectomycorrhizal fungi found in Melbourne, and their hosts, are listed in Table 4.

Table 4. Some exotic ectomycorrhizal fungi associated with exotic trees in Melbourne parks and gardens.

Fungus	Associated tree
Mushrooms	
Amanita muscaria	Pine *Pinus*, Oak *Quercus* or Birch *Betula*
Amanita phalloides	Oak *Quercus*
Hebeloma crustuliniforme	Birch *Betula*
Laccaria laccata	Oak *Quercus*
Laccaria tortilis	Birch *Betula*
Lactarius deliciosus	Pine *Pinus*
Lactarius necator	Birch *Betula*
Lactarius torminosus	Birch *Betula*
Paxillus involutus	Birch *Betula*
Russula integra	Pine *Pinus*
Russula sororia	Oak *Quercus*
Boletes	
Leccinum scabrum	Birch *Betula*
Suillus species such as *Suillus luteus*	Pine *Pinus*
Xerocomus chrysenteron	Oak *Quercus*

The identification of many of the fungi associated with exotic trees needs to be checked, since some of the names are used in a broad sense, and recent revisions show cryptic species to be present in the presumed area of origin. For example, *Paxillus involutus* encompasses at least four distinct species that can be distinguished by DNA sequence data and also host preference and subtle morphological characters (Hedh *et al.* 2008). In addition, ectomycorrhizal fungi of exotic trees in Melbourne have not been fully surveyed, and there are certainly more species to be recorded, such as among the several unidentified species of *Cortinarius* associated with oak in the Royal Botanic Gardens, and in genera such as *Hebeloma* and *Inocybe*.

The species of exotic ectomycorrhizal fungi associated with each host are a small subset of those species growing with the host in their native environment. The particular species that occur in Melbourne will have resulted from a combination of chance events that led to introduction (such as in potted seedlings, with soil, in the days before strict quarantine) and favourable climate and soil, matching that in the country of origin.

The date of introduction of these ectomycorrhizal fungi is difficult to establish due to the paucity of collections from the 19th century

Fig. 6. *Marasmius oreades* fruit-bodies in fairy ring, associated with enhanced growth of grass.

and early 20th century. Even for a distinctive fungus such as *Amanita muscaria* that was recorded from Melbourne by the 1940s (Coleman 1945), the earliest herbarium specimen was collected much later than the time of first notice in the literature, in 1964.

Native ectomycorrhizal fungi also associate with planted Australian native trees such as *Eucalyptus*, *Lophostemon* and *Melaleuca*. Compared to the numerous native ectomycorrhizal fungi in intact vegetation, only a small subset of species occurs with planted native trees in parks and gardens, particularly species of *Laccaria* and the closely related truffle *Hydnangium carneum*, and several other truffles such as *Descomyces albellus*, and species of earthball (*Scleroderma*).

Fungi in bushland remnants

Within greater Melbourne, often embedded in highly urbanised areas, are numerous patches of remnant native vegetation. These patches are of various sizes and in various states of disturbance in terms of diversity of native plants remaining and factors such as weediness. As described above for parks and gardens, numerous fungi are associated with remnant vegetation, as saprotrophs (Table 5), parasites and mycorrhizal partners (Table 6).

The very large bolete *Phlebopus marginatus* is a striking sight anywhere, and persists with remnant *Eucalyptus*, in suburbs such as Blackburn (even pushing aside fence palings as it grows from sturdy button to fully expanded fruit-body). Vegetable caterpillars such as *Cordyceps gunnii* have been recorded in suburbs such as Doncaster, Kew and Warrandyte—their persistence will depend on survival of their hosts, the larvae of ghost moths that feed on wattle roots. Truffles such as *Protoglossum luteum* and *Zelleromyces australiensis* persist in bushland reserves. They are mycorrhizal and also food for small mammals, which dig up the fruit-bodies and hence disperse the spores. However, many small mammals are extinct within Melbourne. How the loss of these dispersers affects the fungi is unknown. Other interesting urban macrofungi include outlying occurrences of fungi typical of the more arid interior of the continent, such as *Battarrea stevenii*, recorded in the 19th century from Altona and in recent

Table 5. Some native saprotrophic fungi observed in urban remnant vegetation in Melbourne.

Jelly fungi
Heterotextus peziziformis
Pseudohydnum gelatinosum
Hydnoid fungi
Mycoacia subceracea
Mushrooms
Macrolepiota clelandii
Marasmius elegans
Melanotus hepatochrous
Mycena clarkeana
Mycena nargan
Mycena viscidocruenta
Xerula gigaspora
Polypores
Antrodiella citrea
Dictyopanus pusillus
Fomitopsis lilaconogilva
Hexagonia vesparia
Laetiporus portentosus
Perenniporia ochroleuca
Polyporus arcularius
Pycnoporus coccineus
Stereoid fungi
Byssomerulius corium
Hyphodontia flavipora
Stereum hirsutum
Stereum illudens

Table 6. Some native ectomycorrhizal fungi observed in remnant native vegetation in Melbourne.

Mushrooms
Amanita xanthocephala
Descolea recedens
Laccaria canaliculata group
Cortinarius abnormis
Cortinarius australiensis
Cortinarius austrovenetus
Cortinarius persplendidus
Cortinarius rotundisporus
Lactarius eucalypti
Russula clelandii
Russula persanguinea
Coral fungi
Clavulina vinaceocervina
Ramaria lorithamnus
Hydnoid fungi
Hydnum repandum group
Puffballs
Pisolithus arhizus group
Truffles
Protoglossum luteum
Setchellliogaster tenuipes
Zelleromyces australiensis

decades from Brighton, Black Rock and remnant woodland in the vicinity of Melbourne Airport.

Larger bushland reserves on Melbourne's outskirts, such as Baluk Willam Conservation Reserve in Belgrave South or Jumping Creek Reserve in Warrandyte, seem to have a diversity of fungi comparable to intact bushland outside the urban area. Smaller reserves can also have a significant diversity of fungi and distinctive native fungi, such as the red-capped *Amanita xanthocephala* (Fig. 7) and the green-capped *Cortinarius austrovenetus*, that persist even in small reserves.

Drinnan (2005) found that among bushland reserves in Sydney there was a relationship between macrofungal diversity and reserve size, with diversity sharply decreasing in reserves less than 2 ha in extent. However, these fruit body surveys consisted of a single one hour visit and yielded a maximum diversity of around a dozen species for a site. Newbound *et al.* (2011) studied 16 sites in River Red Gum woodland along an urban-rural gradient in Melbourne, and found that the composition of the fungal community was correlated with the physicochemical properties of the soil, rather than the degree of urbanisation. The authors used fruit-body surveys (with maximum diversity of 30 species per site) and also a molecular 'fingerprinting' method (terminal restriction fragment length polymorphism analysis) that yielded up to 114 distinct types of fungi per site. The molecular method sampled both macrofungi and soil microfungi and had the advantage of detecting a greater proportion of the diversity present, but the disadvantage of not identifying the samples to named species. In both studies, the different trophic groups of fungi were not separated in some analyses, and it is conceivable that ectomycorrhizal fungi may react differently from saprotrophs. There is much scope for systematic, long-term surveys to assess the relationship between the size and disturbance of reserves and the diversity of fungi.

As in the rest of Australia, many native fungi remain to be identified, either because they are

Fig. 7. *Amanita xanthocephala*, an ectomycorrhizal mushroom, in bushland at Warrandyte State Park.

yet to be formally described, or because comprehensive taxonomic treatments are not available. Thus, large fruit-bodies of the gilled bolete *Phylloporus* can be seen under River Red Gum in remnant bushland, such as at Yarra Bend, but the species concerned has not been identified.

Few rare fungi have been identified in Victoria. The only species listed under the *Flora and Fauna Guarantee Act* is *Hypocreopsis amplectens*. This fungus occurs not far away at Nyora and Greens Bush. These sites will come under increasing pressure, not only from adjacent industrial activities (such as sand mining), but also from nearby urbanisation that has the potential to create increased visitation and usages (such as trail-bike riding) that are incompatible with nature conservation. At Jumping Creek Reserve in Warrandyte, several *Hygrocybe*, including *Hygrocybe fuhreri*, *H. saltorivula* and some un-named species, have been discovered that are at present known only from this site (Young 2000; Fuhrer 2005).

Fungi and climate change

Effects of climate change on the patterns of fruit-body production of macrofungi have already been detected in the Northern Hemisphere (Gange *et al.* 2007; Kauserud *et al.* 2008, 2009). In Australia, from one year to the next, there is much variability in the times that fruit-bodies emerge. This is due to the very variable climate, and as a result, this complicates detection of altered patterns. For the past decade, rainfall in Melbourne has certainly been below the long-term average in most years, particularly for autumn. Anecdotally, this does seem to have reduced the number of fruit-bodies observed, but there are few local studies on the interplay between rainfall and temperature in relation to fruit-body production.

May (2010) found that when Fungimap records of *Agaricus xanthodermus* from Victoria (mostly from greater Melbourne) were plotted by month across the period 2000-2005, there was a distinct peak of records in each year. However, the time of this peak varied from year to year, and in some years fruit-bodies were recorded over more months. It was possible that gaps in records were merely due to lack of recorder activity at that particular time. An additional complication is the considerable difference in climate across Melbourne, particularly the rainfall gradient from west to east, and the patchiness of any given rainfall event within the city.

For rigorous analysis of macrofungal phenology, it will be desirable to have long-term data from particular sites that records both presence and absence of fruit-bodies. Such data has so far been analysed in only one study, that of Newbound *et al.* (2010a) on 25 common species in Red Gum woodlands. These authors found that a relatively simple model incorporating rainfall, evaporation and the time of year could explain the occurrence of fruit-bodies reasonably well. These authors also predicted that climate change to a warmer and drier climate would lead to a reduction in the number of species fruiting and a shortening of the period of fruiting.

The fungi of Melbourne in the future

There are still many unanswered questions about the fungi of Melbourne. In the first place, a more complete inventory of what fungi occur and where they are found would be helpful. Secondly, there is a need for better information about the relationships between fungi and their habitat, in terms of factors such as patch size, disturbance and nutrient levels. Such research is necessary ultimately to allow development of effective conservation and management strategies for fungi.

Future investigations will benefit from emerging on-line accessibility to existing data, both on herbarium collections and also in the form of sight records, particularly through Australia's Virtual Herbarium (http://avh.rbg.vic.gov.au/avh/) and the Atlas of Living Australia (ALA) (http://www.ala.org.au/). The ALA will allow querying of species lists for particular geographic areas, such as a radius around a point (Fig. 8). Naturalists will be able to produce a list of records of fungi (or any organisms), under up-to-date names, from their local bushland reserve or park. This sort of functionality has great potential to encourage increased recording activity. The ALA will also provide tools for field naturalists to upload information, such as sightings and photos of species, to databases such as those maintained by Fungimap. Furthermore, there will be tools to analyse data, such as by relating occurrence of a species to environmental variables such as climate and vegetation.

To best answer ecological questions about the host and habitat preferences of fungi, and to detect changes in fruiting patterns due to climate change, there is a need for data from permanent plots. These can be as simple as a defined area on a nature strip, or a more extensive 'quadrat' in a bushland reserve. The key factor for useful data from permanent plots is to have a clear definition of the area surveyed, and information on factors that might affect the fungi present, such as soil, aspect and vegetation type. It would be possible to create permanent plots by extension of existing activities, such as annual visits to particular sites by groups such as the Fungi Group of the FNCV, or indeed daily walks through a park. However, some assistance in terms of manuals and training is likely to be necessary to set up and establish routines for monitoring permanent plots so that the data is of maximum use for scientific analysis.

There remains a need for many more well documented voucher specimens, especially of native fungi from remnant bushland and of species recorded through Fungimap, but not yet vouchered. Collections lodged in herbaria form both a permanent record of species occurrence that can be confirmed in future, and also the material upon which taxonomic revisions can be based, including description of new species. Emerging molecular techniques offer much promise of rapid identification of both fruit-bodies and environmental samples that contain fungi (such as soil or ectomycorrhizal root tips). However, DNA sequence data from fruit-bodies of known identity needs to be generated to create a 'barcode' library against which new sequences can be identified (McMullan-Fisher *et al.* 2010).

There is a surprising amount of information already known about Melbourne's fungi, and great potential to add to that information and answer important questions, particularly in relation to climate change and host and habitat specificity. Urban areas such as Melbourne will always be key locations in building up data on seemingly less-charismatic groups such as fungi, due to the density of recorders associated with a major urban centre (of currently more than 4 million people). Melbourne is also well-suited for studies on fungi due to the large amount of vegetation of different types and the considerable climatic variation within the greater Melbourne area.

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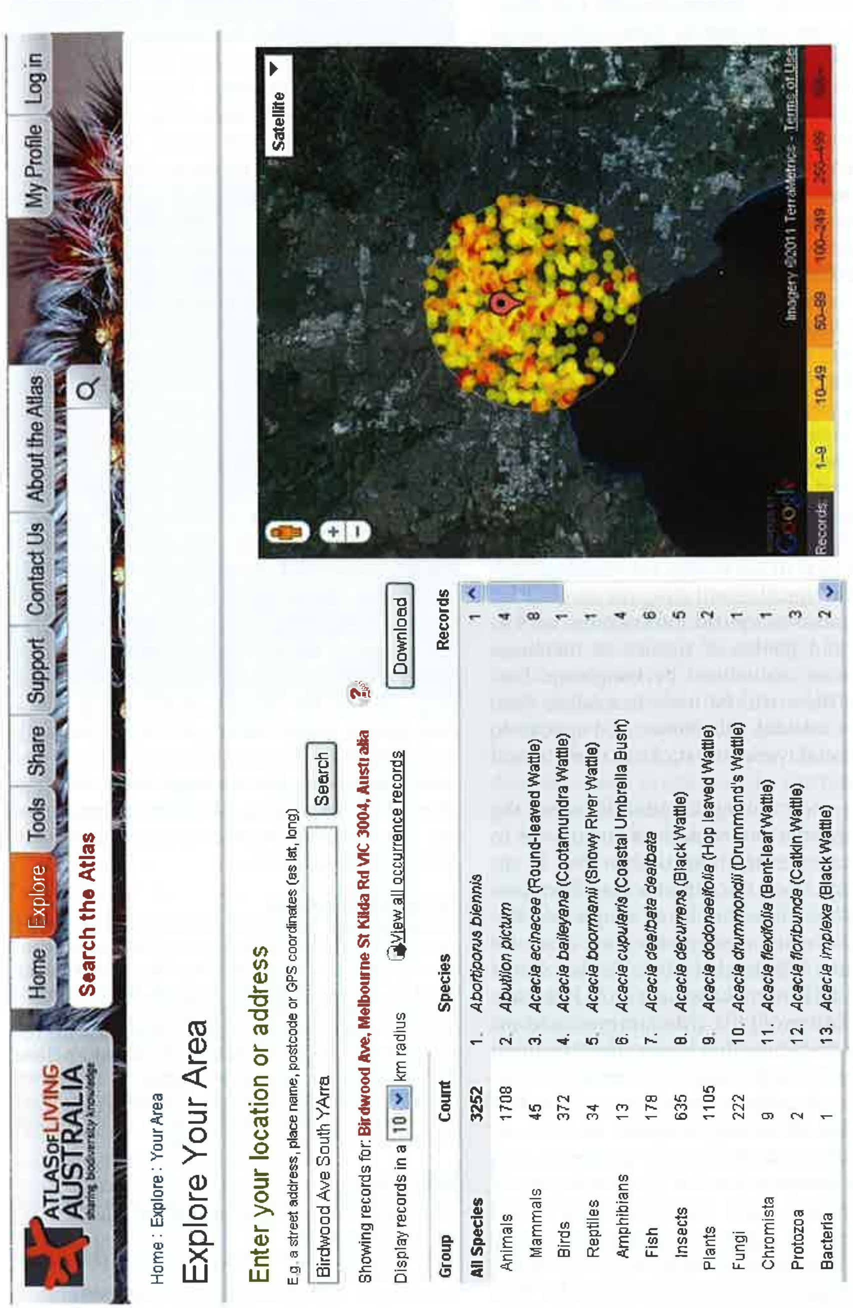

Fig. 8. Screen-shot from the Atlas of Living Australia showing result of search of records of all organisms within 10 km radius around South Yarra in Melbourne, Victoria undertaken in May 2011. The ALA website is in development, and not many fungi are included yet. However, the first organism listed among all organisms within this radius is the fungus *Abortiporus biennis*.

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Fig. 9. *Coprinellus micaceus* growing on wood chip mulch.