CLIMATE CHANGE AND BRISBANE MACROFUNGI

A Critique on how *Climate Change* may affect Macrofungal Biodiversity with Recommendations for their conservation

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A report for the Brisbane City Council

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Front page : *Cortinarius archeri* © A. M. Young

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1. Introduction

1.1 *Climate Change and the Brisbane region*

The *Climate Change and Energy Taskforce Final Report* (Lossee, *et al*. 2007) was presented to the Brisbane City Council in March 2007. The aims of this report were first, to examine possible futures for Brisbane under climate change and declining oil supplies and second, to suggest policies both to lessen their impact and adapt to the new circumstances. Since the Lossee (*ibid.*) report was predominantly concerned with Brisbane's energy requirements, it gave minimal consideration to the range of Brisbane's unique biota which is presently conserved in the city's reserves, parks and gardens.

As a consequence, the Natural Environment and Sustainability branch of the Brisbane City Council commissioned an additional report which would address the impact of climate change on biodiversity in the Brisbane area. This report, *Climate Change and Brisbane Biodiversity* (Low, 2007) was presented to the council in August 2007 with the specific purpose of rectifying this omission. While the Low report provides an excellent analysis of the likely impacts of climate change on Brisbane's biota, it necessarily only provides an overview (although some specific taxa are mentioned). The Low report does, however, provide responses to four key problems which have been summarized below:

1. The vulnerabilities faced by the city's biodiversity;
2. The adequacy of current strategies in addressing those biodiversity vulnerabilities;
3. The key actions that could address any identified inadequacies; and
4. The critical information gaps in relation to biodiversity vulnerabilities that need urgent redress to facilitate timely and informed action.

The Low (*ibid.*) report offers suggestions (Section 4.2) on species at risk, and to that end considers animal pollinators such as birds and mammals, the monitoring of tree death, seed storage, rare plant cultivation and captive breeding populations for animals. Problems with introduced fish species released from aquaria are also discussed.

Information gaps as noted in item 4 of the above list, are discussed in Section 5 of the Low (*ibid.*) report, and all three are of interest to this document: species at risk, fire hazard and control, and weed eradication. The Low report does not mention macrofungi in any context. This is fully understandable, however, because a full consideration of the impacts of climate change on macrofungal biodiversity is far too specific to be addressed within the broad treatment of biodiversity that the Low report is designed to provide.

A second climate change report currently in draft form (Low, 2008), concentrates on climate change in the Brisbane region and how it will affect specific communities and threatened species. This second Low report contains a list of eucalypt taxa that may be at risk of local extinction under the conditions of climate change and as these are also the very species that form associations with the macrofungi, their loss from Brisbane's biota would have quite serious implications for the macrofungi concerned. As with the earlier report, no mention is made of the macrofungi.

1.2 *Information on climate change and the Brisbane macrofungi*

This report follows automatically from the Low (2007, 2008) reports in providing information on a subset of Brisbane's biota: the macrofungi. There is currently no Australian document which investigates the effects of climate change on the macrofungi within any Australian ecosystem. Since these organisms are known to be crucial to the survival of the ecosystems as a whole, the absence of such information is presently an enormous gap in the knowledge that allows successful understanding or actions to minimise the effects of climate change. It also follows that the principles and conclusions espoused by the Low reports are supported fully where they are found to apply to the macrofungi. It is also accepted that this document can only provide an introduction to the problems of understanding the reaction(s) of the macrofungi to climate change. It does, however, represent a "base-line" study that was undertaken with the hope that it will inspire future research to obtain the additional data needed to confirm or amend our suppositions once that data becomes available.

During the preparation of this report two additional major documents were released which have relevance to this report: the CSIRO paper on Climate Change, Biodiversity and Australia's Reserve System (Dunlop & Brown, 2008) and the Queensland Government Report on Climate Change (Qld EPA, 2008). The Dunlop & Brown report discusses climate change in all its aspects and outlines how it will affect the nation's reserves, forests and their biodiversity. It covers broad principles and it is not intended to treat any particular group of organisms within the Australian biota in detail. Similarly, the Queensland government report espouses comparable principles but from a Queensland-centric viewpoint, as well as discussing the likely impacts on human society. Both papers completely accept that climate change is occurring and that action must be taken to minimise its effects on the environment.

1.3 *The scope of this report*

During the preparation of this report, the authors investigated a sample (Appendix A) of 10 of the major reserves, forests and woodlands managed by the Brisbane City Council. Our discussions and conclusions are necessarily dependent upon those observations, however it should also be noted that a considerable amount of forest and woodland within the city's boundaries inhabits privately owned lands. These areas were not examined in any way, however their vegetation will be essentially similar to one or more of the sample parks, forests and reserves that were visited during the survey. For this reason, they may be considered as being part of the area covered by this report and some brief observations and suggestions have been provided on this matter at the end of section 5.

1.4 *The aims of this report*

1. To consider (briefly) the critical importance of the macrofungi in the Brisbane biota;

2. To document areas of Brisbane where the various ecological groups of macrofungi are to be found and the relevance of those regions to biodiversity of the macrofungi;

3. To examine those areas and determine their vulnerability to various impacts imposed or exacerbated by climate change; and

4. To suggest methods of ensuring conservation and preservation of the macrofungi and the ecosystems they support.

2. A Brief Overview of the Macrofungi

2.1 *Defining the term "macrofungi"*

The term "macrofungi" can be simply defined as those fungi whose fruiting bodies may be readily seen with the unaided eye as distinct from the microfungi in which the fruiting structures can only be properly seen using a hand lens or microscope (Hawksworth *et al.*, 1996; May & Pascoe, 1996; May, 1997; Fuhrer, 2005). Most of the fungi that can be frequently observed during wet weather in any park, garden or reserve in the Brisbane region are therefore members of the macrofungi. A number of descriptive words are commonly applied to these organisms by the Australian public and these include *mushrooms*, *toadstools*, *puffballs*, *jelly fungi* and *bracket fungi*. With the influx of Asian and European immigrants, other terms are coming into local usage especially where many types of edible macrofungi are sold in supermarkets. Words such as *shiitake*, *morel*, *oyster mushroom*, *straw mushroom*, *boletus* and C*hinese mushroom* are therefore becoming more frequent, if not common.

A selection of four species of macrofungi is shown in Plate 1. These were chosen as representative species occurring in the Brisbane region, and that are most likely to be recognized as such by the public. It includes two gilled species (toadstools), a puffball relative (earthstar) and a bracket fungus displaying pores on its lower surface.

Certain organisms such as slime moulds are frequently considered by the public as "macrofungi", although most mycologists agree that slime-moulds are not strictly members of the fungal kingdom at all (Walker, 1996a; Fuhrer, 2005). Nevertheless, the larger slime moulds are frequent in the Brisbane region and are often the subject of interest to its residents when they occur on litter, mulch or grass in the parks and gardens and mycologists are invariably called upon to identify them. Slime moulds (Plate 2, A) will only be briefly touched upon in this report.

2.2 *What is a macrofungus ?*

The structures that are called mushrooms, toadstools, etc. are not the body of the fungus itself but its "fruit" (Cleland, 1934; Claridge, Castellano & Trappe, 1996). A simple analogy is that of an apple-tree and an apple; the tree is the parent organism and the apple is its fruit with the reproductive function of producing and dispersing the seeds it contains. In the same way, a macrofungus has a parent organism and the so-called fungus that we see is a "fruit" for producing and dispersing fungal reproductive cells while the fungus itself is hidden in the substrate underneath the fruiting body. An apple tree is always visually present to the observer whether it is in fruit or not, however the body of a macrofungus is generally invisible to the observer because it is hidden inside the substrate (soil, litter, wood, etc.) through/on which it is growing (Hood, 2003). The macrofungi are often ignored or overlooked as critical components of ecosystems but they are always present in any ecosystem at all times of the year; the problem is that they do not "impinge upon the observer's consciousness" unless they are fruiting.

Generally, the body of a fungus (called a mycelium) appears like a fluffy mass of tiny threads called hyphae (the mass rather resembles cotton wool) that ramify through the rotting wood, litter or soil (Cleland, 1934; Aberdeen, 1979; Hood, 1992; Fuhrer, 2005). For these reasons, the fruiting bodies of the macrofungi are usually the first evidence that a particular species is present at a site, and because mycelia in general cannot be distinguished one from another, it is generally the differences in fruiting bodies that allow mycologists to separate the species (Young, 2005a).

2.3 *Propagation in the macrofungi*

The macrofungi propagate by spores, microscopic particles that are analogous to seeds but so small that a reasonable approximation would show that about 100 spores placed end-to-end are required to cover a distance of 1mm (Cleland, 1934; Walker, 1996a). While they are sporulating, most species of macrofungi produce enormous numbers of spores and these are often deposited in such vast quantities that powdery dust appears on the surfaces beneath the gills of toadstools (Young, 2005a). These spores are commonly dispersed by wind and so the Brisbane region is not an isolated habitat, but rather is constantly receiving and transmitting fungal spores from and to the surrounding areas.

2.4 *The number of macrofungal species and their fruiting patterns*

Australia probably has somewhere between 5,000 and 20,000 species of macrofungi (Bougher & Syme, 1998; Young, 2005a), an extremely variable estimation which simply reflects the poor knowledge of the Australian macrofungal biota. New species are being recorded and described each year and there are very few mycologists doing such work (Pascoe, 1991; May, 1997; Young, 2005a). It is therefore a matter of extrapolation and guesswork to estimate the number of macrofungal species likely to occur in the Brisbane region, however given the usually ideal conditions and the very large variety of habitats present, a suggestion of between 5,000 and 10,000 species in total would not be unreasonable. If this is then coupled with the fact that perhaps as much as 50% of these species may not yet be formally discovered and described, the difficulties of assessing abundance and rarity, or whether a species should be given a status of endangered or threatened become obvious. All too often the knowledge that would allow such a decision to be made is not available (Bougher & Syme, 1998).

It is also important to note that macrofungi are notoriously erratic in their fruiting patterns. Seemingly ideal conditions may produce very few fruiting bodies, or small amounts of rain may produce mass fruitings of some taxa, but the reasons are still uncertain. Temperature, rainfall and humidity are certainly the principle "triggers" for fruiting (Strassma *et al.*, 2001), but whether or not a particular species will appear under given conditions is still not fully understood (Pascoe & Shipton, 1996). Most mycologists would agree that obtaining a complete census of the macrofungal species in a given area requires many years of surveying with updates being made each season (Straatsma *et al.*, 2001; Syme, 2004; Ratkowsky & Gates, 2005; Robinson & Tunsell, 2007; Krivtsov *et al.*, 2007). It may take 15 to 20 years (or more) (Straatsma *et al.*, 2001) to be confident that more than 90% of the species in a given area are finally accounted for, simply because vagaries of climate may only produce ideal fruiting conditions once in that period (May, 1997; Watling, 2004; Young, 2005b). It should be stated here that the only checklist of macrofungi for Queensland is that of Bailey (1913) which is extremely outdated and does not reflect the true speciation of the Queensland macrofungal biota let alone their abundances or distributions.

2.5 *Lifecycles of the macrofungi*

The life cycles of the macrofungi can be very conveniently divided into three main types (May, 1997; Fuhrer, 2005; Grey, 2005):

2.5.1 Recycling species that utilize dead plant (or less frequently, dead animal) tissues as the nutrient substrate (saprophytes). These are to be found in grasslands, sand-dunes, heaths, woodlands and forests; amongst plant litter, on all types of soil containing plant-derived humus or decayed carcass residues, and on all stages of rotting wood.

2.5.2 Parasitic species which attack living plants and obtain their nutrients from a living host. The parasite may or may not kill the host, and host death may be very rapid or prolonged over a number of years. Some parasites cannot survive without a living host to support them; other species make the best of both worlds and can first live parasitically on the host, but then utilize its dead tissues saprophytically while another living host is located (e.g. *Armillaria* spp.). Any living photosynthetic plant, grass, herb, shrub or tree is vulnerable.

2.5.3 Mutualistic species (ectomycorrhizal) which go into a beneficial and usually essential partnership on the roots of photosynthetic (green) plants, especially shrubs and trees.

2.6 *The lack of knowledge about the Brisbane macrofungi*

Representatives of all three groups are known to occur in the Brisbane area, however as was outlined regarding the situation in Western Australia (Bougher

& Syme, 1998), the precise identity of the species present and their relative abundances and distributions in the Brisbane region remain uncertain. Recent estimates suggest that perhaps 20,000 species of macrofungi exist in Australia and perhaps as few as one quarter of the total number have been scientifically documented (Young, 2005a). Even if these estimates are incorrect and the number of documented macrofungi is increased to 50% of the total number of estimated species, it does not alter the fact that there is currently an enormous lack of knowledge about the macrofungal species of the Brisbane region.

Plate 1 Examples of four species of macrofungi found in the Brisbane area.

A, *Amanita ochrophylloides*, a mycorrhizal gilled species; B, *Armillaria luteobubalina*, a parasitic gilled species; C, *Laetiporus sulphureus*, a wood inhabiting bracket fungus;
D, *Geastrum triplex*, a "puffball" relative and recycling species. © A. M. Young

3. The Essential Role of Macrofungi in Brisbane Ecosystems

3.1 *Introduction*

From the perspective of the untrained observer, the macrofungi differ in one enormous way from the mosses, ferns, conifers and flowering plants: the macrofungi are apparently not "permanent members" of the local environment. Whilst this is completely wrong, it is very understandable: the macrofungi seem to appear sporadically for short periods of a few days (often in large quantities) and then apparently disappear for the rest of the year. The problem with the above erroneous perspective is that the observer fails to understand that he/she is seeing only the fruiting structures of the macrofungi and that the parent mycelia are more or less permanent but unseen members of the various ecosystems (May, 1997; Hood, 2003).

3.1.1 Difficulties in working with macrofungi Except for short-lived ephemerals, botanists studying flowering plants (and mosses, ferns and conifers) have an advantage in that the object of study will usually still be extant in a particular location for much longer periods of time than a few days, and material of the species can be easily recollected. For extended studies, it is possible that the same plant specimen can be easily relocated for years or even decades. Conversely, without access to molecular techniques [which necessitate pre-existing catalogues of macrofungal DNA structures or the actual production of them, (Moncalvo *et al.*, 2002)], a mycologist can only produce accurate identifications of macrofungi using their fruiting bodies. Unfortunately, these are not only generally fragile, they also rapidly collapse, rot and disappear. The fruiting bodies of some species (especially those of the genus *Coprinus*) have a lifespan of only 1–3 hours (Cleland, 1934; Orton & Watling, 1979) while that of many others may be limited to several days. Some of the very "woody" bracket fungi (eg. *Gandoderma*, *Fomes* or *Phellinus*) have fruiting structures that can persist for a number of years (Fuhrer, 2005) and continue to actively sporulate, but these are exceptions rather than the rule. The first author's own observations include a massive fruiting body of *Ganoderma australe* which sporulated more or less annually in the Lamington National Park for a period of at least eight years until destroyed by vandals.

Because of this generally "brief lifespan" of the macrofungal fruiting body, they are far more difficult to study and "fungal communities are notoriously difficult to assess comprehensively in the field" (Humphrey, Ferris & Quine, 2003). Whilst it may be known that a particular species is present at a location, the appearance of its fruiting bodies in any one year (or even once in a decade) cannot be predicted with certainty (May, 1997; Robinson & Tunsell, 2007; Krivtsov *et al.*, 2007). Macrofungal fruiting is known to be initiated by the cumulative effects of at least some of the factors of climate, location, human interference, fire or other physical elements (Cleland, 1934; Willis, 1957; Pascoe & Shipton, 1996; Walker, 1996b; Young, 1999; Young, 2005b) and possibly other 'as-yet-unknown' factors as well, but precisely which factor (or combination of factors) determines the appearance of the fruiting bodies on any one occasion is presently unknown for most species. It is equally rare that a macrofungus can produce a mycelial structure so large and persistent at a site that it can be identified purely on the basis of that mycelium. The best known example is the enormous mycelium of the 'toadstool' *Armillaria ostoyae* of the Malheur National Forest in eastern Oregon. The mycelium is estimated to cover 2,200 acres and be at least 2000 years old (Johnson, 2000).

3.1.2 Macrofungi as permanent members of ecosystems The macrofungi must always be recognised as permanent members of an ecosystem, whether in vegetative or fruiting stages and whether they are active or dormant (Pascoe & Shipton, 1996; Watling, 2004). Adverse climatic conditions may force the mycelia of some taxa into dormancy, but other species will be active and accumulating nutrients for the next occasion which favours the production of fruiting bodies and successful sporulation. This means that while many Australian ecosystems (such as the Brisbane parks and reserves that are predominantly eucalypt forest or woodland) may seem dry and unfavourable at certain times of the year, at least some species of macrofungi will nevertheless be more or less active in or around the roots of mycorrhizal partners and in dead wood where moisture has been retained.

Because all true fungi lack chlorophyll (Hood, 1992; Walker, 1996a; May, 1997) and therefore cannot photosynthesise, they must obtain their nutrients from pre-existing organic sources. For this reason, the macrofungi (as already noted in Section 2) employ one or more of three methods to supply their requirements: saprotrophism (chemical decomposition of dead animal or plant tissues), parasitism (obtaining the required nutrients from still living hosts, as either obligate or facultative parasites), or mutualism (forming mutually beneficial mycorrhizal associations with photosynthetic plants) (Pascoe & Shipton, 1996).

3.1.3 The roles of macrofungi in the Brisbane region In the following parts of this section we consider the essential roles macrofungi perform in Brisbane ecosystems including: recycling, pathogenic effects, animal food resources, and mycorrhizal partnerships. A final section has been included which examines the roles of the macrofungi as environmental indicators. The authors' aim is to demonstrate, in general terms, how the macrofungi are affecting the biota of the Brisbane region, and numerous examples of all aspects covered will be found in the various parks, reserves and forests maintained by the City of Brisbane. Specific examples will be discussed later in the report (see also Appendix A).

3.2 *Recycling* The macrofungi have an enormously important role to play in recycling dead plant (and to a lesser extent, dead animal) tissues in the environment. Literature simply based on the assumption that macrofungi are present and active on dead organic material is plentiful (Cleland, 1934; Willis, 1957; Shepherd & Totterdell, 1988; Rossman, Tulloss, O'Dell & Thorn, 1998; Fuhrer & Robinson, 1992; Watling, 2004; Tait, 2007), but there is also an abundance of information describing the rates of decay, the chemicals involved, and why the recycling process is so critical to the health of the individual ecosystems (Krivtsov *et al.*, 2007; Rillig & Allen, 1999; Conant *et al.*, 2008; Olsrud *et al.*, 2004).

3.2.1 Litter The term "litter" is here applied to the accumulation of dead plant residues that form a layer over the soil within a plant community. The litter builds up over time and will be seen to be composed of small twigs, dead leaves and at least some small branchlets under approximately one centimeter radius. (This definition provides an arbitrary method of separating larger branches from the general litter because the larger branches are usually disposed of by those macrofungi specifically involved in rotting wood.) The litter can become extremely deep over time, especially if fire has not occurred for several years, and a cross section through the litter layers reveals that the leaves and twigs in the upper levels are mostly intact, while at the lower levels, disintegration is nearing completion and the best description for this lowest level is humus (Young, 1999; Krivtsov *et al.*, 2007). Where the litter layer is very thin, these levels may not be clearly defined. Depending upon available moisture, fungal hyphae (individual threads of the fungal mycelium) penetrate through the litter layers and begin the process of decomposition. Fungi are unique in that they are able to conduct two processes simultaneously: not only do they possess enzymes able to split apart the cellulose and lignin molecules of woody tissues, they can also grow through those softened and disintegrating tissues to reach those parts of the plant material in which the decay process has yet to start (Hood, 2003; Pascoe & Shipton, 1996). This is quite different from the bacteria which essentially remain surface organisms because they are usually unable to penetrate through the hard plant tissues. On many occasions, macrofungal activity and growth is so intense, that upon disturbance of the litter layer or mulch heap, white or coloured mycelia will be found to be enveloping most of the plant fragments and unifying them into a nearly solid mass. An example of this process in its early stages is shown in Plate 3-A.

It is accepted absolutely that microfungi are also an important part of the litter recycling process, but the macrofungi are equally important and their activity (Plate 3-C) accelerates litter decomposition (Watling, 2004). During this process, simple chemical compounds that can be utilized by green plants are released to the soil, and so the macrofungi recycle the nutrients that would otherwise be "locked-up" in the litter. All activity ceases only once the litter is fully decomposed into substances that contain no energy for fungal activity. Lastly, the dead macrofungal tissues themselves are rotted by bacteria or attacked by various components of the soil biota (e.g. nematodes), thus further contributing to the nutrient supplies that are made available to the ecosystem's plants (Krivtsov *et al.*, 2007).

Another beneficial effect of macrofungal activity in the litter layer is that the material becomes extremely friable and porous/spongy. This means that the litter layer can now absorb considerable amounts of water during precipitation events and store it as a temporary reservoir. Invertebrate activities, however, can also markedly affect the moisture contents of soils (see paragraph below). The mulching effect of the litter layer is now so well known that it is routinely promoted on television gardening shows as an essential component of a healthy garden. Forest litter plays the same mulching role in the Brisbane ecosystems.

3.2.2 Invertebrates and litter macrofungi Arthropods (insects and terrestrial crustaceans) penetrate through the softened litter, and soil organisms such as worms and grubs burrow up into the lower layers and bring plant fragments into their tunnels (Klironomos *et al.*, 1997). In this way, partially-decayed plant fragments are physically incorporated into the soil horizon itself, thus providing fragments that can be readily attacked by those macrofungi that live deeper in the soil beneath the litter layer. The mycelia of many of these soil-inhabiting macrofungal species also penetrate upwards into (at the very least) the lower levels of the litter layer. Furthermore, the activities of the invertebrate biota provide the additional positive effect of increasing the rate at which surface water can penetrate into the soil (Colloff *et al.*, 2008), and this, in turn, also benefits the activities of the macrofungi.

3.2.3 Logs, invertebrates and macrofungi The process of macrofungal recycling of fallen logs can be considered in much the same way as that of litter, although the complete reduction of logs to the point where virtually no residues remain takes a much longer period of time, simply because much larger volumes and more compact tissues are involved when compared with litter fragments (Hood, 2003). Many factors control how fast any log is recycled by the macrofungi but these include: climatic variables such as temperature, rainfall and humidity; the physical location of the log with respect to shade/sun, water and humidity; the size and composition of the log (tree species); whether decay has started prior to tree fall; what macrofungal species are present in the region; and insect/invertebrate presence (Lawrence & Milner, 1996; Junninen, 2007).

Another aspect to be considered is macrofungal succession. A newly fallen log is rapidly colonised by several species of macrofungi which then compete for the log's nutrients, however their activities are not readily visible until fruiting commences. Observations by the first author show that hardwood logs in the local rainforests may commence with large crops of the Australian shiitake (*Lentinus lateritia*) which then dies out to make way for other species such as the rainbow bracket fungus, *Trametes versicolor*. Other macrofungal species will, in turn, become dominant for undefined periods during which time they will extract from the log the particular set of nutrients they require. When these are exhausted, the macrofungal mycelium dies to be replaced by yet other macrofungal species that are able to utilize a portion of the nutrients that remain. Over time, any given log will exhibit a significant progression of macrofungal species as it converts from solid wood to friable humus (Plate 3-B).

The role of arthropods (principally insects and terrestrial crustaceans) is also noteworthy because, depending upon the species, they utilise either (or both) the wood and the fungi as food, depending upon the species (Lawrence & Milner, 1996). These arthropods burrow into the log's wood to produce tunnels through which air and moisture can more readily penetrate. Often, the insects attack those portions of the log that have already been softened by macrofungal activity and in turn assist the fungi to penetrate deeper and more rapidly into the wood. The fungal mycelia and associated fruiting bodies may or may not be utilised as food however it is certain that macrofungi and arthropods are frequently synergistic as regards their rotting activities within logs (Hood, 1992).

The first author's own observations over a 25 year period in South East Queensland show that soft wood logs (hoop pine, *Araucaria cunninghamii*, or bunya pine, *A. bidwillii*) rot much faster than hardwood logs (*Eucalyptus* spp.). In addition, it is noted that rainforests and wet eucalypt forests (or even sheltered gullies in drier areas) naturally produce accelerated rotting of both litter and logs due to the higher moisture levels, however the rates are reduced in open woodland where sunlight penetrates readily and drier ground surface conditions prevail for much of the year. Nevertheless, large eucalypt logs can act as water reservoirs in that they absorb considerable quantities of water during wet periods and can therefore allow fungal decay to continue within the log even when the log exterior is apparently completely dry and climatic conditions do not favour macrofungal fruiting. In the same way, insects will persist within the log and its reduction to humus will always proceed, albeit at a much slower rate. These general observations support the hypothesis that eucalypt woodlands depend on the attacks of insects (or other invertebrates) to assist in the decomposition of both logs and litter. Under very dry conditions, litter and logs may build up to such an extent that fire becomes the only natural way in which their mineral nutrients can be released back into the soil.

3.2.4 Dung recycling and macrofungi Another important decomposition role performed by macrofungi is that of recycling herbivore dung (Young, 1978). There is an abundance of literature on the breakdown of sheep, cattle and horse dungs by the macrofungi (numerous species of which exist only on this specialized habitat) and it can be reasonably expected that marsupial dung will be equally subject to the activities of the macrofungi. The Brisbane City Council permits horse-riding along the track systems of many of their parks and reserves. As a consequence and during the course of this study, piles of horse dung were not only seen on the tracks, but specimens of a macrofungus (*Panaeolus antillarum*, which occurs only on horse and cow dungs in Australia), were observed growing on the older deposits.

The droppings of herbivorous marsupials are generally in the form of small pellets (Lamont *et al.*, 1985; Claridge, 1993; Lohmeyer, 1994) which desiccate rapidly and are certainly significantly smaller than the dung deposits of cows and horses. The ultimate process is, however, identical: the marsupials extract what nutrients they can from the herbage they eat and deposit faecal pellets which are composed largely of undigested cellulose fibres intermixed with digestive tract debris. These pellets are acted upon by coprophilous macrofungi which assist in their breakdown in a manner not unlike that of the litter fungi (Lohmeyer, 1994). Ultimately, the dung pellets become part of the litter layer and the humus.

3.2.5 Dead animal residues and macrofungal recycling To a lesser extent, the macrofungi also have a role in the recycling of dead animal remains and they operate in two distinct ways: they can actively decompose dead animal tissues, or they can assist with the decomposition of the nutrient residues from decayed corpses. Certain species are able to utilise the extremely decay resistant protein-based substrate of keratin, the principle component of feathers and hair/fur and are therefore able to recycle these substances. While many of these species are microfungi, others such as *Onygena piligena* are macrofungi and can be seen on the disgorged pellets below owl roosts (May, 1997; Hubalek, 2000; Marchiso, 2000). The second method is employed by the Australian ‘ghoul fungus’, *Hebeloma aminophilum* (Plate 4-A). This species flourishes in the nutrient enriched soil directly underneath a decayed corpse and continues the decomposition of the nitrogenous compounds to be found there (Hilton, 1978; Miller & Hilton, 1987; Fuhrer, 2005).

3.2.6 Summary of macrofungi and recycling In summation, the macrofungi play a critical role in recycling dead plant material in any natural form, and may also assist with the degradation of certain types of dead animal tissues. Without their presence, the reduction of logs and litter to humus would almost cease in wet forests and this would lead to enormous biodiversity changes in those forests (if not outright extinction of the entire ecosystem), while in dry eucalypt woodlands the resulting fire hazards would be increased considerably. The recycling role of the macrofungi in Brisbane’s parks, reserves, woodlands and forests is therefore extremely important.

3.3 *Pathogenic effects*

Macrofungal pathogens are very common in plant communities but their attacks are usually noticed when they cause damage or death to large shrubs and trees (Corkill, 2006). There are a number of macrofungal species that can act as pathogens, however some of the more common genera are: *Armillaria*, *Ganoderma*, and *Junghuhnia*. Many of the bracket fungi (e.g. various species of *Ganoderma*, *Junghuhnia*, *Phellinus*) are tree pathogens and they obtain entrance to the uninfected host through wounds on the trunk, branches or roots (Hood, 2003) (Plate 4-B). These wounds occur naturally through the effects of wind or damage by branch fall from a higher tree, however there is no doubt that some wounds are caused by arboreal mammals such as possums and there are also instances where human activity has allowed infection (Simpson, 1996). The species *Phellinus noxius* has become an important tree pathogen in South East Queensland where it attacks hoop pines, rainforest trees and a wide range of hardwood tree species in urban parks, reserves and gardens (Hood, 2003).

Species such as *Armillaria luteobubalina* (Plate 1-B) may infect a tree when the spores fall on freshly exposed living tissues, however *A. luteobubalina* can also move from one host to another by means of underground root-like structures called rhizomorphs. These grow out through the soil to the next suitable host and the fungus spreads outwards in a steadily increasing circle of destruction. Species of *Armillaria* are important parasites in moist forests and woodlands in eastern Australia where they are significant native tree pathogens (Kile & Watling, 1983). *Armillaria luteobubalina* is widespread in South East Queensland and therefore the Brisbane region (Hood, 2003).

3.3.1 Macrofungal parasites and ecosystem biodiversity Host death may be extremely rapid or prolonged, depending upon the particular macrofungal species involved. In mature forests, macrofungal pathogens are relatively sparsely and randomly distributed such that the loss of a single tree is not of major concern (Simpson, 1996). Indeed, it may be considered that the role of macrofungal pathogens in a mature forest is to ensure that old or weak trees are eradicated and in so doing, that their subsequent death and collapse creates clearings in the forest, which allows new seedlings to replace the parent trees. In this way, pathogenic activity can be considered a natural and useful process because it actually encourages the maintenance of biodiversity by ensuring that short-lived pioneer plant species have opportunities to establish and reproduce before the newly opened gap in the forest is recolonised by the larger, long-lived tree species. Some parasitic macrofungi remain in dead logs for an extended period and continue their lifecycles as recycling species (facultative parasites; e.g. *Armillaria luteobubalina*), while others are unable to exist without living tissues as a nutrient source (obligate parasites; e.g. *Cytarria septentrionalis*).

3.4 *Animal food resources*

The macrofungi are now recognised to constitute an extremely important food resource for Australian mammals, molluscs (snails and slugs), arthropods (at least insects and tiny terrestrial crustaceans) and some reptiles (Cleland, 1934;

Claridge, 1993; Claridge & Lindenmayer, 1993; Lawrence & Milner, 1996; Bougher & Syme, 1998; Hood, 2003; Young, 2005a; Grey, 2005, Vernes, 2007).

3.4.1 Macrofungi as an invertebrate food resource Species of the Boletaceae are extremely rapidly attacked by insects and the fruiting bodies may rot almost as soon as the spores are being produced (Plate 4-C). The parasitic bracket fungi are also attacked by various types of beetle larvae and the large fruiting bodies may become spongy masses riddled with larvae tunnels (Bougher & Syme, 1998). Invertebrates other than insects also attack various macrofungal fruiting bodies. For example, the ghost fungus, *Omphalotus nidiformis* (Plate 3-B), will be found to be host to enormous quantities of tiny crustaceans if the gills/lamellae of the undersurface are examined. This same fungus is also heavily attacked by giant snails when it occurs in rainforests and the fruiting bodies of virtually all other macrofungi are attacked by slugs and snails if they are present where the fungus is fruiting (Young, 2005a). Some species of tiny flies owe their abundance to the numbers of macrofungal fruiting bodies that appear in due season.

3.4.2 Macrofungi as a reptile food resource Australian reptiles are not often considered as dependent upon the macrofungi for food, although there is ample evidence that reptiles in other countries do use macrofungi as a food resource (Hailey *et al.*, 1997; Moskovits & Bjorndal, 1990; Brode, 1959). In South East Queensland, the giant black skink (*Egernia major*) has been seen feeding on a species of *Lactarius* during autumn (Plate 2-B,C) (Young, 2005a). This is an area that deserves further research as it is quite possible that other Australian reptilian species may have some mycophagous tendencies as well.

3.4.3 Macrofungi as a marsupial food resource Apart from the invertebrates, Australian native mammals display considerable dependence upon the macrofungi as a food resource. A major research project (in which the authors participated) is currently underway at the University of New England. This project is investigating the use of the subsurface macrofungi by mammals of the Gibraltar Range National Park in northern New South Wales (Vernes, 2007). (These particular fungi are also called "truffle-like" fungi, although they generally have no direct relationship with the true truffles of Europe, which are not native to Australia.) The truffle-like fungi are extremely common in eucalypt forest and woodland where they are mycorrhizal with the eucalypt tree roots (see section 3.5) and various species are to be found throughout the year in the first few centimeters of the soil, or just under the litter layer (Plate 4,D). Mammals scratch in this soil layer to unearth the fruiting bodies (usually more or less spherical) and are guided to them by the odours these macrofungi produce. It is now known that many small species of Australian mammals depend to some extent on these truffle-like fungi in their diet. For some of the smaller mammals such as bettongs, the truffle-like fungi may form over 80% of the mammal's total diet (Claridge, Castellano & Trappe, 1996). Other Australian mammals that utilize the macrofungi for food include bandicoots, bushrats, potoroos, small wallabies and possums, and the evidence suggests that the macrofungi may form more than 20% of their total food intake. The data from the UNE project also indicates that larger wallabies and forest kangaroos forage for these macrofungi as well, but at lesser rates of consumption.

3.4.4 Macrofungi and marsupials of the Brisbane region In the Brisbane region, at least four species of small marsupial utilise the hypogeal (or truffle-like fungi) as a food resource to some extent. These are the northern brown bandicoot (*Isoodon macrourus*), the long-nosed bandicoot (*Perameles nasuta*), the rufous bettong (*Aepyprymnus rufescens*) and the long-nosed potoroo (*Potorous tridactylus*) (Claridge, 1993; Claridge, Castellano & Trappe, 1996; Ryan, 1995; Vernes, 2007). (Note: *Potorous tridactylus* ssp. *tridactylus*, the subspecies found in the Brisbane region, has vulnerable status under both Queensland's "Nature Conservation Act (1992)" and the Commonwealth's "Environment Protection and Biodiversity Conservation Act 1999".) Of these four, the fungi may account for as much as 40–50% of dietary intake for the bandicoots and the bettong, but this increases to approximately 80% of the diet of the long-nosed potoroo. In the case of the latter mammal, the presence of the macrofungi is essential to its survival (Strahan, 1983). There is also the strong likelihood that at least some of the native rats and mice (Vernes, 2007) utilise macrofungi as food in the Brisbane area, however precise data on this particular aspect remains to be collected.

3.4.5 Summary of the macrofungi as an animal food resource The macrofungi, as a food resource, are crucial to the survival of at least some of the small mammal populations in the Brisbane region. The macrofungi also form an extremely important food resource for invertebrates and for at least some reptiles. (For a discussion on mammal-fungus-plant relationships, seesection 3.5.3 below.)

3.5 *Mycorrhizal partnerships* Many species of macrofungi form highly beneficial partnerships with higher plants. These relationships are referred to as "mycorrhizae" (*mycorrhiza* = "fungus root"). Macrofungi, due to the physiological processes involved, form a particular type of mycorrhizal association which is more specifically termed an "ectomycorrhiza". This implies that the fungus forms an external sheath on the surface of the root tip, although the exact structure is somewhat more intricate. In an ectomycorrhizal association, the macrofungus and plant grow together to form a complex structure in which the mycelium of the fungus penetrates the roots of the plant but does not actually enter into the root cells. Instead, the fungal hyphae interweave between the outermost cells (cortex) of the root thus forming a structure called the "Hartig net". At the same time, a fungal sheath develops around the outside of fine root tips. The ultimate result is that although the fungus never enters into any plant cells, the plant and fungal tissues are in very intimate contact with each other. In this way, the two separate organisms can exchange chemical substances across the thin layers of cell walls and membranes that separate them (Harley, 1969; Young, 2005A). Microfungi also form mycorrhizal partnerships, however the relationships are somewhat more complex and are outside the scope of this report.

3.5.1 Macrofungal mycorrhizae and their functions Mycorrhizae are now known to be essential for the successful growth of many shrubs and trees and more than 80–90% of the world's flowering plants and conifers form mycorrhizal partnerships (May, 1997). In simplified terms, the fungus acts as a secondary root system and it can respond very quickly to favourable conditions of moisture (e.g. rainfall after a period of dry weather). The hyphae grow out from the root, penetrate the soil and absorb mineral nutrients and water. These are brought back to the root and pass into the plant cells. In return, the fungus absorbs some of the sugars and other substances sent to the roots by the leaves as well as being provided with a "safe haven" inside the root if soil conditions become too dry and unfavourable. When conditions are again conducive for growth, the fungus can respond rapidly, certainly much more quickly than can the plant's own roots (Pascoe & Shipton, 1996). It is worth noting, therefore, that plants in mycorrhizal relationships are often more resistant to diseases, such as those caused by microbial soil-borne pathogens, as well as being more resistant to the ravages of drought (Azcon-Aguilar & Barea, 1993).

3.5.2 Macrofungal ectomycorrhizae and the Brisbane ecosystems
Ectomycorrhizal relationships involving various groups of macrofungi are known to be critically important for a very large number of Australian trees and shrubs, especially the Myrtaceae, which includes eucalypts, paper barks, bottle-brushes, kunzeas and ti-trees (e.g. *Eucalyptus*, *Corymbia*, *Angophora*, *Tristania*, *Lophostemon*, *Kunzea*, *Leptospermum* and *Melaleuca*). Other Australian plants that form ectomycorrhizal partnerships include (but are not confined to) the pine-like "she-oaks"(*Allocasuarina*, *Casuarina*), the wattles (*Acacia*), Rhamnaceae (*Pomaderris*) and species of native beech (*Nothofagus*) (May & Simpson, 1997). These partnerships are so important that without the macrofungal partners, survival of the various plant species would be doubtful. Eucalypts and other members of the Myrtaceae are often found on impoverished soils such as sand dunes and without the macrofungal partners that aid in nutrient absorption, such locations would be difficult,

if not impossible, for the various eucalypts and other mycorrhizal species to colonise (Bougher, 2007; Stol & Trappe, 2007). Many areas of Brisbane have a poor, sandy loam which nevertheless supports a vigorous heath, woodland or forest ecosystem based on the taxa outlined above, but this is only made possible by the ectomycorrhizal partnerships shared with the macrofungi.

Macrofungal genera known to form ectomycorrhizal relationships and already collected by the authors from the Brisbane region include: *Amanita, Austroboletus*, *Boletellus*, *Boletus*, *Cantharellus*, *Cortinarius*, *Craterellus*, *Dermocybe*, *Hebeloma*, *Hydnum*, *Hygrophorus*, *Inocybe*, *Laccaria*, *Lactarius*, *Phylloporus*, *Pisolithus*, *Ramaria*, *Russula*, *Scleroderma*, *Strobilomyces*, *Thelephora, Tricholoma* and *Tylopilus*. There is every reason to believe that species of the above genera are in ectomycorrhizal relationships with the myrtaceous and she-oak members of the Brisbane biota. There are also a number of subterranean or litter growing "truffle-like" macrofungi including such genera as: *Gymnomyces*, *Hydnangium*, *Hymenogaster*, *Setchelliogaster*, *Thaxterogaster* and *Zelleromyces*. This latter group is not only ectomycorrhizal, it also provides a vitally important food resource for mammals (Claridge, Castellano & Trappe, 1996).

Some of the ectomycorrhizal macrofungi are capable of producing fruiting bodies under what would normally be considered to be very unfavourable conditions. Species of the genus *Pisolithus* are very frequent in dry eucalypt woodland and their fruiting bodies often erupt in masses in the dry gravel at the edges of bitumen roads (Young, 2005a). The authors have occasionally seen specimens emerging through bitumen paved areas in school grounds when there are mature eucalypts close by and occasionally receive reports from various schools regarding the same phenomenon.

3.5.3 Macrofungal ectomycorrhizae and the Brisbane marsupials The macrofungal-mammal-tree relationship has been known for some time but it essentially means that small mammals such as bettongs depend on the truffle-like macrofungi for as much as 80% of their diet. The macrofungus is in an ectomycorrhizal partnership with the tree roots and therefore both tree and fungus need each other for normal survival. The mammal requires the tree to form the habitat in which it survives and the fungus as its principle food, while the fungus benefits by having its spores scattered in the droppings of the bettong (see section 3.3.4 above). Truffle-like fungi often produce strong odours that are readily detectable by the mammals when they are foraging (Claridge, Castellano & Trappe, 1996; Young, 2005a).

3.5.4 Summary of macrofungi and mutualistic partnerships This report emphasises that not only are the macrofungi important as mutualistic (ectomycorrhizal) partners for the Brisbane forests and woodlands, they are essential to their survival. Without these fungi active in their above roles as both mutualistic partners and marsupial food resources, the current parks, reserves and forests would not survive, or if they did they would be in an extremely reduced/modified form and plant growth would be either stunted, or at least for some taxa, impossible. In addition, the Brisbane region would ultimately lose several of its small species of marsupials. The ectomycorrhizal macrofungi are also extremely important in their role of protecting their forest partners against both disease and drought. The importance of the macrofungi in overall ecosystem survival cannot, therefore, be overestimated.

3.6 *Environmental indicators* Lichens (which are mostly symbiotic unions of a fungus and either a green alga or a cyanobacterium) are very good pollution indicators because they are more or less permanent fixtures on the surfaces of rocks, trunks or branches or other suitable surfaces. Thus, the disappearance of pollution-sensitive species can be quickly noted (Stevens, 1997). Conversely, macrofungi are more difficult to utilise in this role because appearance of the fruiting bodies is so erratic. Nevertheless, it is known that some groups of taxa (e.g. the Hygrophoraceae) are very good indicators of pollution or chemical applications in pastures or forests if long term records are available. The use of the macrofungi as "excellent bioindicators" has already been noted in the northern hemisphere where the reasons cited for this particular attribute are that the macrofungi have a "large number of species, specialization's and important ecological functions" (Amaranthus, 1998).

3.6.1 Macrofungi as pollution indicators Some species of macrofungi behave in the same way as lichens, in that they are very sensitive to physical factors in the environment such as "pollution" by artificial fertilizers when they are applied to pastures (Arnolds, 1981, 1983; Boertmann, 1985). By extension, this can also occur when enriched nutrient flows enter ecosystems which normally have very low nutrient levels (Young, 2005b): the macrofungi no longer appear in areas where they have been common and may take up to ten years before they return after the removal of the source of the pollution (Young, 2005b). Whether other groups of macrofungi behave similarly is not known, however it can be supposed that at least some will. The macrofungi can also be used to detect the presence of trace elements or heavy metals (Nikkarinen & Mertanen, 2004; Svoboda, L., Havlíčková, B. & Kalač, P., 2006; Stijve, 2007).

3.6.2 Macrofungi as biodiversity indicators The macrofungi are also known to be bioindicators of at least some aspects of the 'overall health' of an ecosystem. The report submitted to the Queensland Department of Primary Industries (Young, 1999), indicated that the macrofungi respond to the effects of both fire and the presence of grazing cattle in forest areas. Whilst the report is necessarily limited due to the timeframe of its survey period (and therefore its inability to account for any taxa that may be extremely sensitive to the effects of fire and/or cattle grazing over long periods of time), some general indications of macrofungal responses can be obtained. Supportive data on the effects of both cattle and fire are provided by Burrows *et al.* (2002), who found that if the combined regime persisted indefinitely, the effects were so great as to alter the ecosystem permanently.

Fire by itself causes 'some to considerable' immediate damage to the litter inhabiting and lignicolous species because their overall abundance and diversity is heavily diminished immediately after the fire simply because their substrates have been almost totally destroyed. The report indicates however, that both these parameters return to their pre-fire levels within 2–4 years of the initial disturbance, although it is uncertain if any hypersensitive species [e.g. the Hygrophoraceae (Young, 2005b)] (Plate 3-D) may require much longer time periods for recovery. The effects of cattle are somewhat similar, however the report suggests that the destructive effects are rather more intense. While the report does not extensively explore the reasons for this difference, it may be because the impacts of cattle are on-going rather than isolated events, and the constant disturbances of soil and litter (possibly exacerbated by the effects of 'over-stocking') may become sufficiently large to prevent normal mycelial colonisation of the litter, while the constant inflow of nitrates in the animals' urine and faeces will seriously affect at least some taxa. The report also contains information which suggests that the combined effects of both fire and cattle- grazing will produce considerable damage to the macrofungal litter taxa and it would be reasonable to expected that severe damage will require longer periods for regeneration to take place, especially if unfavourable climatic conditions prevail during that recovery period.

3.6.3 Macrofungi as climate change indicators The macrofungi are also known to be sensitive indicators of climate change because they respond very rapidly to their biotic environments (Krivtsov *et al.*, 2003). Kauserud *et al.* (2008) have discussed how the climatic changes taking place in Norway are already affecting the fruiting periods of the macrofungi of the boreal forests. Similar results are now being found for British macrofungi (Anon, 2007) and the Dawyck Botanic Garden project (Krivtsov *et al.*, 2003) is now being used to model the effects of climate change on a macrofungal population. For Australia as a whole, and for the Brisbane region in particular, such modelling is not yet possible on a large scale, simply

because the data for so many taxa and specific geographical areas is not available.
The Dawyck project concentrated on a small area which nevertheless has so far recorded over 200 taxa from its measured plots. This long timespan project began in 1994 and is still in progress. In order to obtain meaningful data on the environmental effects of climate change on the macrofungi, it is essential to implement dynamic research programs which allow ongoing expansion of the datasets in a controlled manner (Krivtsov *et al.*, 2007). Likewise, the Victorian "Fungimap Project" was commenced in 1995 (Grey, 2005) and has recorded geographical locations for up to 105 taxa as at the current date. The records are now in excess of 20,000, however they are not necessarily applicable to all Australian locations simply because data collection has not commenced in so many areas due to the lack of volunteers. There is no doubt that this project contains data that could be utilised to ascertain how at least some species are responding to climate change in terms of their alterations in geographical ranges.

Finally, the IBISCA project was set up in 2003 by Prof. Roger Kitching at Griffith University with the aim of recording the appearance of macrofungal taxa on designated rainforest plots across an altitudinal gradient in the Lamington National Park. This area was selected because it represents a region considered to be "ecotonal" in nature and therefore very sensitive to any climatic change effects. This project has not yet had sufficient time to collect representative data.

3.7 *Section Summary*

- Macrofungi are, by their nature, more difficult to to study than higher plants, and fungal communities require long-term assessment in the field.

- The macrofungi are permanent members of all Brisbane ecosystems and play essential roles in recycling, pathogenic activities and mutualistic partnerships.

- The Brisbane faunal components of native mammals, reptiles and invertebrates all utilise macrofungi in their diets. For many small invertebrates, the macrofungi are their principal food resource; for some smaller mammals, the dietary reliance on macrofungi reaches 80% of all food intake and without the macrofungi, certain of the smaller marsupials would become extinct in the Brisbane region.

- The mutualistic partnerships of the macrofungi are essential to the survival of the Brisbane forests and woodlands.

- Macrofungi have enormous potential as excellent bioindicators of ecyosystem health, pollution and climate change, provided data on their activities is accumulated.

Plate 2 A, *Fuligo septica*, a slime-mould often found on garden mulch; B, *Lactarius clarkeae*, a mycorrhizal species sometimes utilised as food by the giant black skink, or "land mullet"; C, *Egernia major*, (common name "land mullet"),

the giant skink found in the Brisbane region; A & B © A. M. Young; C © N.A.Fechner.

Plate 3 A, *Ramaria filicicola*, on leaf litter and showing mycelial penetration; B, *Omphalotus nidiformis*, wood recycler, also used by invertebrates as a food source; C, *Marasmius* sp. a litter-recycling gilled fungus; D, *Hygrocybe miniata,* a recycling

species that is extremely sensitive to agricultural or environmental pollution © A. M. Young.

Plate 4 A, *Hebeloma aminophilum*, on soil under the bones of a decayed wallaby; B, *Phellinus* sp. parasitic on rainforest tree; C, *Tylopilus* sp. a boletoid species heavily attacked by insect larvae (arrow shows site of attack); D, a

hypogeal/underground (*Hymenogaster* sp.) macrofungus used by mammals as food. © A. M. Young.

4. Climate Change, Macrofungi and Brisbane's Forests & Woodlands

"Essentially, all models are wrong, but some are useful". Box & Draper (1987).

4.1 ***Climate Change***

Whether climate change is occurring, and if so, the underlying causal factors of such change (see 4.2.1), have been the subjects of a multitude of papers, symposia and other national and international information transfer programs (e.g. Miller *et al.*, 2002). This report accepts that changes in climate are occurring on a worldwide basis and are therefore also occurring in Australia because it is an integral component of the world biosphere. Such a position has been fully accepted at both Commonwealth and State Government levels (CSIRO, 2007; Qld EPA, 2008).

4.1.1 Documents on climate change For brevity, this report's account of climate change in Australia is based primarily on three documents which were prepared for the Australian Commonwealth Government and a fourth which was prepared for the Queensland State Government. These are the NRMMC Report (2004), the Climate Change Report (CSIRO, 2007), the National Reserve System Assessment (Dunlop & Brown, 2008) and the Climate Change in Queensland Report (Qld EPA, 2008). The CSIRO Climate Change Report (2007) documents past, present and predicted future climate regimes for Australia and is the most recent climate change account encompassing the entire Australian region. The other two Commonwealth documents listed also describe the presently proposed effects of climate change, but concentrate on what impacts these could have on Australia's ecosystems/national reserve systems and their biodiversity. They also proffer recommendations for developing appropriate management protocols. The Queensland EPA (2008) document outlines prospective changes to various climatic parameters and discusses how these changes will influence the environment and human society in Queensland. Some potential solutions are offered for some of these problems.

Other high-impact environmental threats such as the incursion of exotic taxa, appear to be both exacerbated by (and synergistic with) climate change, and the outcomes of, and management of, these predicted disasters are well-documented. Examples include: modelling the future ranges of exotic woody weeds under climate change (Kriticos *et al*., 2000); pests and pest management (Sutherst, 2000); and national strategies for weed management (NRMMC, 2006). For the Brisbane region specifically, a report on climate change and biodiversity has been submitted to Brisbane City Council (Low, 2007), while a second report (Low, 2008) discussing climate change and threatened species or communities is now in the final stages of preparation.

It is notable that no previous report on the effects of climate change on the macrofungi of the Brisbane region exists, and that macrofungi were omitted from all Australian climate change reports published at either national or regional level.

4.2 *Modelling Climate Change and the macrofungi*

Considerable use has been made of computer models to simulate how the earth's biosphere may react to alterations of atmospheric parameters such as rainfall, temperature, carbon dioxide levels and humidity. The results are used to predict possible changes to either environments as a whole or to various aspects of their constituent biota such as survival, fecundity, distribution, diversity, physiology, etc. (Kriticos *et al*., 2000; Sutherst, 2000; Krivtsov *et al.*, 2003; Hughes, 2003; Nitschke & Innes, 2008; Kauserud *et al.*, 2008). Most papers now published on climate change make reference to computer modelling to some extent. While modelling is an extremely useful tool, caution should be exercised against "blindly accepting" the published analyses of any model's predictions. This is because the researchers themselves suggest that the models may not be wholly accurate in their calculations due to such factors as: too many environmental variables that cannot be accounted for in either data or the model itself (Sutherst *et al.*, 2007); too many gaps remaining in the known data set to allow accurate modelling of the effects (Fransson *et al*, 2001); or simply that an immense amount of data (which may be unavailable) is required before an accurate model can be produced (Weltzin *et al.*, 2003; Pendal *et al.*, 2004; Krivtsov *et al.*, 2003).

4.2.1 Debate on the causes of climate change There are also conflicting views as to the cause(s) of the climatic changes now occurring. Recent articles (Evans, 2008; Chapman, 2008) argue that increases in atmospheric CO_2 levels are not the underlying cause of the recorded climatic variations. As the scientist who wrote the "FullCAM" carbon accounting model for the Australian Greenhouse Office, Evans agrees that global warming has occurred but states that there is no data to prove that the warming has resulted from increases in atmospheric CO_2 levels. Evans then goes on to state that satellite readings now indicate an opposite trend in that there is presently a cooling of the earth's surface which may continue for the next decade. Chapman confirms Evan's concepts of a "cooling earth" and suggests that rather than atmospheric CO_2 levels, the changing temperatures are linked very closely to the solar sun-spot cycle which is now reaching a minimum.

A similar debate has begun in the USA and both the validity of the anthropogenic CO_2 model for climate change and its underlying probity are being both challenged (Monckton, 2008) and supported (Hafemeister & Schwartz, 2008). The contentious nature of the argument has recently gained momentum, with the editor of the newsletter of the American Physical Society requesting a full scientific debate on the subject (Marque, 2008).

The authors of this report do not have the expertise to analyse the views of Evans, Chapman and others, but it is prudent to acknowledge that there is a considerable body of opinion which now runs completely counter to the currently prevailing concepts. Should temperatures fall as Evans, Chapman and others are predicting, very different impacts will be felt by Brisbane's ecosystems and the macrofungi they contain.

4.2.2 Models specific to Australian ecosystems and the macrofungi

The computer model developed for a particular ecosystem will depend on the conditions specific to that ecosystem (Krivtsov *et al.*, 2004) and because the climate, flora, fauna and fungal components of Australian ecosystems are not directly equivalent to those of the northern hemisphere, models derived from such ecosystems may be relevant only in very general terms when applied to Australian ecosystems. For example, Parsons, Lindroth & Bockheim (2004) investigated litter decomposition rates of *Betula papyrifera* (paper birch) under elevated carbon dioxide and ozone levels and found that the rates of decomposition appear to be largely dependent on the quality of litter, and hence the species producing it. The litter dynamics of Australian eucalypt forests are not homologous with that of either boreal deciduous or coniferous forests, and thus implementing a similar investigation within eucalypt habitats may illicit radically differing conclusions .

Where Australian macrofungi are concerned, caution on model choice is well advised. This is because whilst there are numerous computer-generated models outlining the responses of the macrofungi to climate changes in northern hemisphere ecosystems, there are, to the knowledge of the authors, none specifically designed to suit Australian environmental and ecological parameters. Due consideration also needs to be given to the fact that there is a myriad of niches within ecosystems, but that climate change research usually considers broad ecosystem dynamics rather than the much more restricted models that are necessary for climate change impacts on individual species. It is highly probable therefore, that any computer-based climate change model designed for non-Australian ecosystems will produce more-or-less erroneous results and thus conclusions, when it is trialled within an Australian context. For Australian ecosystems, the problem is exacerbated even further due to the lack of the necessary long-term data sets on both climate and macrofungi, which are required to construct a meaningful, and reasonably accurate, predictive model (Hughes, 2003).

4.3 ***Climate Change and the Brisbane region***

Using desktop research and stakeholder feedback, Hobbs & McIntyre (2005) constructed a conceptual definitional model of Australian ecosystems, which was hypothetically segregated into 10 agro-climatic zones using characteristics of climate (moisture index, growth index and seasonality) and vegetation (based on soil fertility, geology, presence/absence of a tree layer, and whether the understorey was grass- or shrub-dominated). Their final framework was an adaptation of the classification system proposed by Hutchinson *et al.* (1992, 2005) - in which 18 agro-climatic zones had been identified for Australia - and was supplemented with ecological knowledge of habitat replacement and modification variables, including the nature of land-use practices.

The variables selected were intended to effectively describe the major differences in landscape sensitivity, and expressions of ecological dysfunction, between zones (Hobbs & McIntyre, 2005). The resultant 10 zones were assigned to the bioregions and subregions defined within Thackway & Cresswell's (1995) framework: *An interim biogeographic regionalisation for Australia* (IBRA 5.1 – a landscape-based model), as had the 18 classes of Hutchinson *et al.* (1992, 2005), in an attempt to produce some degree of homology in communications between ecologists and conservationists involved with landscape management.

Dunlop & Brown (2008), with the assistance of McIntyre, assessed the impacts of climate change on Reserve areas within Australia, utilizing the zones of Hobbs & McIntyre (2005), who in turn based their categorizations on the spatial analyses of Hutchinson *et al* (1992, 2005). They expanded upon these models by also considering data on current and projected rainfalls; native vegetation; net primary productivity; fire frequency and season; and elevation (Dunlop & Brown, 2008). Hobbs & McIntyre (2005), and thus Dunlop & Brown (2008), defined the region incorporating coastal NSW and coastal Queensland as far north as Fraser Island as the "Subtropical moist" agro-climatic zone.

Characteristic of a subtropical moist zone, the Brisbane region contains wet and dry sclerophyll forests and woodlands (dominated by species of *Eucalyptus* or close allies and interspersed with species of *Allocasuarina/Casuarina*, *Acacia*, *Banksia*, *Melaleuca*, etc.); coastal heath (species of *Leptospermum*, *Banksia*, *Acacia*, *Xanthorrhoea*, etc.); some fern gullies and vine thickets; paperbark swamp structures (*Melaleuca* spp.), and littoral mangrove swamps (*Avicennia* sp.) (Appendix A). Each of the above forest and woodland types provides an extremely important habitat for macrofungi. Despite their usually "hidden nature" (Lilleskov & Bruns, 2001), the macrofungi are integral to the continued functioning and survival of Brisbane's forests, woodlands, heathlands and grasslands and it is highly probable that modifications to the macrofungal component of habitats could drive dramatic impacts on ecosystem function (M. Dunlop, *pers. comm.*). Insufficient is yet known about the macrofungi of Brisbane mangrove woodlands to make similar statements as above, however it is entirely probable that some highly specialised macrofungi do live within the mangrove woodlands, and to that extent, the mangroves are an important habitat for those species.

4.3.1 The Brisbane region as an "ecotone" In broad ecological terms, the Brisbane region may be also be considered an "ecotone", or intermediate region, between the tropical and temperate climes of the eastern coastline of Australia and it is consequently an area of high biological diversity and fragility (Low, 2007). It is also defined as a climate change "hot spot" (Qld EPA, 2008), with additional factors such as increased anthropogenic pressures through population growth, land degradation and habitat loss. Ecotones are more likely to be damaged (local species reduction) or disappear (local species extinctions) if major changes occur in either of the bordering systems, and under climate change, this may result from their inability to survive in any form, or because they steadily migrate northwards or southwards as the climate changes. It is partially for this reason that the IBISCA project was located in the Lamington National Park region of South-East Queensland because this unique habitat was considered to be a more sensitive bioindicator of the possible effects of climate change impacts than the Brisbane region.

4.3.2 The parameters of climate change Both the CSIRO Report (2007) and the Dunlop & Brown Assessment (2008) indicate several major areas of concern with respect to climate change and outline both how the climate change parameters have altered and postulate future trends. These principal parameters are:

a. atmospheric carbon dioxide levels,
b. temperatures,
c. rainfall/precipitation, and
d. sea-levels.

The Commonwealth climate change report (CSIRO, 2007) indicates that its climate change models produce results with varying outcomes, such that for any nominated area, a range of parameter changes is possible. Furthermore, Dunlop & Brown (2008) emphasise that there is still considerable uncertainty about the effects of these shifting parameters; that some of these changes may affect our ecosystems more than others; and that questions as to how species distributions and abundances will alter remain unanswered simply because there is insufficient data on how ecosystems will react to these changing circumstances (see Section 4.2). This latter statement is in full agreement with the conclusions of Hughes (2003). Each of these parameters will now be considered with respect to both the macrofungi and the Brisbane region as a whole. Whilst this "baseline" report will consider each of the parameters separately, it needs to be borne in mind that they undoubtedly interact together on the various ecosystem components, and that there will be synergies (e.g. drought, rising temperatures and their combined effects on fire frequency, intensity and extent) or unforeseen conflicts in their various impacts that will require future investigation. In that sense, this report must be considered as only a starting point for future research.

4.4 Atmospheric Carbon Dioxide (CO_2) levels Documented levels of global atmospheric CO_2 have risen from 280 parts per million (ppm) in 1750 to 379 ppm in 2005. This increase (70%) largely took place over approximately the past 40 years and exceeds any changes in CO_2 levels for the past 10,000 years. Computer models indicate that atmospheric CO_2 could increase to about 970 ppm by 2100 if no changes in human activity occur (CSIRO, 2007; Dunlop & Brown, 2008). The consequences of this increase in CO_2 are uncertain, however there is evidence to show that green plants will be affected and that there is a strong probability that the higher levels of CO_2 will further contribute to the "greenhouse effect' thus exacerbating overall global warming.

There is a plethora of literature documenting how increasing atmospheric CO_2 levels will affect various parts of the environment within an ecosystem, including effects on: **roots** (Norby, 1994; Norby & Jackson, 2000; Tingey *et al*., 2000); **soil aggregation** (Rillig *et al*., 1999); **plant pathogens** (Chakroborty & Datta, 2003); **arbuscular mycorrhizae** (Gavito *et al*., 2002; Gavito *et al*., 2003; Fitter *et al*., 2000); **litter** (Conant *et al.*, 2008; Kemp *et al.*, 1994; Parsons *et al*., 2004; Bronson *et al.*, 2008); **soil arthropods** (Klironomos *et al.*, 1997); **soil microbial populations** (Rice *et al.*, 1994); and the **overall root symbiont community** (Fransson *et al*., 2001).

Considering the above assortment of variables, it is manifestly evident that the effects of rising CO_2 levels on any ecosystem may be quite profound and operate in completely unpredictable ways. More important however, is the fact that a number of the above cited papers also indicate that regardless of the variable being explored in the research, it is the overall array of all the ecosystem components in combination that elicits the critical responses of the ecosystem under consideration. For example, increased CO_2 levels may increase leaf-fall because of increased plant growth. However, equally important will be the fact that nutrient qualities of the leaf-fall will change, therefore the quantity and ratios of soil nutrients will alter and this will also be combined with potential shifts in the relevant pH balance. These changes will impact directly on decomposition rates, soil fauna and mycorrhizae (O'Neill, 1994).

According to Hughes (2003), increased CO_2 levels will almost certainly lead to enhanced growth rates of eucalypt woodland and forest trees. This directly impacts on the Brisbane region because the majority of the parks, reserves and forests are dominated by myrtaceous tree species. The rise in CO_2 levels leads to an increase in photosynthesis and improves water efficiencies of the trees but conversely leads to a reduction of nitrogen in the overall plant system (Larigauderie *et al*., 1994).

For the Brisbane macrofungal species, the effects of increased CO_2 on their activities can not be considered in isolation because the macrofungi are an integral part of the various Brisbane ecosystems and as has been outlined above, these ecosystems will be affected in various ways by the increased CO_2 levels. This level of complexity is beyond the scope of this baseline treatment and for simplicity, this document sources available literature to consider how the effects of increased atmospheric CO_2 levels will affect macrofungal mycorrhizal activity, parasitism or litter/wood recycling while nevertheless indicating possible Brisbane ecosystem interactions where necessary.

4.4.1 Ectomycorrhizal taxa Significant research has been undertaken, particularly over the last two decades, on the effects of rising CO_2 levels on the ectomycorrhizal species, primarily because this group of macrofungi is extremely important in forestry plantations. Northern hemisphere species of *Picea* (spruce) and *Pinus* (pine) require ectomycorrhizal partners for successful growth, as do their myrtaceous and casuarinas counterparts in Australia.

It seems probable that, provided appropriate water and nutrient levels are in the soil (Staddon *et al.*, 2003), increased CO_2 levels will promote increased activity and hyphal expansion of ectomycorrhizal and arbuscular mycorrhizal fungi (Treseder & Allen, 2000). Expanding on this, the results of Zak *et al.* (1993) and Kandeler *et al.* (2008) imply that increased atmospheric CO_2 may be facilitating the reciprocal flow of carbon into the soil, in conjunction with the increased mineralisation activity of ectomycorrhizal fungi. This implies that an enhancement of the overall carbon cycle is a likely outcome of elevated atmospheric CO_2.

Conversely, increased nitrogen levels in soils have a repressing effect on ectomycorrhizal macrofungal activity (Treseder & Allen, 2000; Lilleskov *et al.*, 2002; Tarvainen *et al.*, 2003). Increased soil nitrogen concentrations, such as commonly occur in proximity to urban and agricultural areas, have immediate implications for Brisbane's eucalypt forests and woodlands because these ecosystems are generally situated on very poor soils where the activities of ectomycorrhizal fungi are essential for their survival. Eucalypt litter is by nature reasonably nutrient-deficient because the parent plants withdraw nutrients, especially phosphorus, prior to leaf abscission (Attiwill *et al*., 1978).

Australian ectomycorrhizal macrofungi generally function in soils with poor to very poor nutrient levels. Research thus far indicates that their activities will probably not be impeded if nutrients in the deposited litter are reduced (see section 4.4.3) because it is nitrogen enrichment (or more specifically, decreasing the C/N ration or lignin/N ratio) that impedes ectomycorrhizal activity (Cotrufo & Ineson, 1996; Aerts, 1997; Carney *et al.*, 2007). Thus far, the data seems to indicate that, in and of themselves, increasing levels of CO_2 (in the absence of simultaneous increases in nitrogen concentration) will increase activity in the ectomycorrhizal community rather than depress it (Treseder & Allen, 2000; Lilleskov *et al.*, 2002; Tarvainen *et al.*, 2003; Zak *et al.*, 2000). An unfortunate aspect of rising CO_2 levels is that species composition of the ectomycorrhizal community may possibly be altered with the loss of at least some of the original biodiversity, however the remaining community should probably still retain considerable (if not equivalent) species richness (Fransson *et al*., 2001).

4.4.2 Parasitic taxa The effects of increased CO_2 levels on parasitic macrofungi are far more difficult to predict because, to the knowledge of the authors, there appears to be little information on which to base such predictions. Chakroborty & Datta (2003) found that as CO_2 levels increase, microfungal plant pathogens become more aggressive in their activity: more spores are produced, growth rates increase, attacks on hosts increase and there is greater genetic alteration in the parasite. It is plausible that these results could be extended to macrofungal parasites as well and suggests that experimentation involving wood-rotting pathogens and CO_2 levels needs to be given serious attention. O'Neill (1994) also indicated that parasitic microfungi may be of considerable concern as atmospheric CO_2 levels rise. Although O'Neill was referring only to soil-borne microfungal parasites, at least some of the macrofungal parasitic species are also found in soils and therefore it is again plausible to consider their likely accelerated activities and the need for experimental monitoring. Although it is accepted that other factors contributed to the event, it is postulated that the recent outbreaks of *Phellinus noxius* in Brisbane (Corkill, 2006) may have been exacerbated by the increasing atmospheric CO_2 levels. *Phellinus noxius* is traditionally associated with tropical environments, distribution strictures being characteristically imposed by temperature. At this stage, the general indications are that macrofungal plant pathogens/parasites will probably not be affected deleteriously by rising atmospheric CO_2 levels, but rather that their activities will be enhanced, and this may have negative implications for long term survival of their host-species in the Brisbane forests.

4.4.3 Litter recycling taxa In the case of litter taxa, the effects of increasing CO_2 levels are difficult to predict with any degree of certainty, given the complex nature of dynamic ecosystems. The effects of CO_2 on one particular variable could turn out to be counterbalanced by the completely opposite effect on another variable involved in either the nitrogen or carbon cycles. O'Neill (1994) suggested that as atmospheric CO_2 levels rise, nutrient levels in the litter-fall will decrease because the plants are more active about translocating nutrients out of leaves that are about to fall. (These remarks are also supported by the presented facts in section 4.4 above.) Nevertheless, Australian macrofungal litter recyclers are already adapted to litter with low nutrient levels (Attiwill *et al*., 1978) so that, at least as far as the litter recycling macrofungi are concerned, little alteration can be expected, particularly if the increased CO_2 result in increased litter deposition. If all other variables remain the same, this increased litter horizon may result in more abundance of the litter macrofungi if conditions are suitable for their activities. Similarly, the wood recyclers are expected to have minimal effects from the increased CO_2 levels. Nitrogen and lignin concentrations will also affect the mechanics of ecosystem carbon cycling in a variety of ways (Norby *et al.*, 2001), depending upon the climate, season or location of the habitat.

While the reduced levels of other mineral nutrients in the litter seem to be more or less constant, at least some eucalypts in the Brisbane region concentrate manganese in the leaves before they fall (Rogers & Westman, 1997). Until recently the significance of this accumulative habit was still hypothetical but there is now some evidence that manganese is crucial for litter decomposition by the macrofungi and that the manganese concentrations may be a mechanism by which the trees facilitate nutrient recycling, particularly of scarcer elements. Nitrogen and phosphorus availability appear to be the controlling factors in litter decomposition during the initial stages of the decay process however the biodegradation of lignin (a principal component of wood) dominates the later phases of decay - for up to as much as five years (Berg *et al*, 2007).

Manganese peroxidase (MnP) is a ligninolytic enzyme which is synthesized by the majority of white-rot macrofungi, and a range of soil-inhabiting saprophytic macrofungi including members of the genera *Agaricus*, *Agrocybe*, *Collybia*, *Marasmius*, *Panaeolus*, *Phallus* and *Stropharia*. To date, no other micro-organisms have been shown to produce manganese peroxidase, and the litter and wood rotting macrofungi are the only group of organisms known to have evolved a significant ability to decompose lignin (Hofrichter, 2002).

Manganese ions are ubiquitous within soils and wood substrates, and are preferentially oxidized by MnP. Ultimately, this process results in the degradation of lignin, humic acids and a range of other recalcitrant substances. Litter decomposition will progress provided that sufficient Mn is available in the system, and may be further regulated by both the plant species involved, and the chemical and physical properties of the litter (Berg *et al*, 2007).

Climate has also been demonstrated to influence the rate at which these decay processes progress (Berg & Staff, 1980; Berg & Matzner, 1997), but it was also shown that climatic effects diminished with the onset of later stages of decomposition. This would suggest that fungal peroxidase activity functions independently of temperature, at least to the extent to which it has been investigated, and that therefore climate change may have minimal impact upon the functioning of wood-decaying macrofungi. An important inhibitor of the rate of lignin degradation is the nitrogen concentration in the relevant substrate, through its suppressant effect on production of the ligninase system in fungi (Berg *et al*, 2007).

In summary, the litter recycling macrofungi are crucial to litter and wood decay in the natural environment since only they are able to produce the relevant enzymes that will facilitate degradation/mineralisation of the "difficult to biodegrade" chemical components present in both wood and litter. Nitrogen enrichment reduces this ability, but the present information suggests that the litter recycling taxa will function either independently or with enhanced activity if atmospheric CO_2 levels rise.

4.5 Temperatures Many climate change models (CSIRO, 2007; Dunlop & Brown, 2008) predict that the annual average temperature for Australia will increase by up to 2°C by 2030, and up to 7°C by 2070. It is therefore essential to understand how these increases will affect the vegetation that forms the framework of the Brisbane forests, reserves and parklands. References cited by Low (2007) suggest that some of the extant eucalypt species in the Brisbane area will be affected to some degree by the changes and some may even become extinct within their current ranges, however Low (*ibid.*) also stresses that there are so many ambiguous variables in climatic scenarios that exactly what will eventuate in any specific circumstances is essentially unpredictable. As Low (*ibid.*) records, by 2070 Brisbane may have a climate similar to that currently experienced in Rockhampton, but some plant species of both Brisbane and Rockhampton overlap, therefore whilst some may become extinct locally, others will not and may possibly extend their natural range. Low (2008) provides a list of those species of eucalypt he considers most at risk and which, if lost, would have considerable impact on the ecological functioning of Brisbane's forests and woodlands. It is very possible that species of eucalypt that currently have more northerly distributions may replace the "at risk" taxa and as Low (2008) indicates, if these colonising species have ecological functions similar to the taxa they replace, then impacts on Brisbane's ecosystems may be minimal.

4.5.1 Changes to Brisbane's forests and woodlands At least some species of eucalypt native to the Brisbane region will survive, and there may be a steady invasion of other species of eucalypt from the north (Low 2007). What is certain is that existing forests, parks and reserves will persist, but there is a probability that the species diversity, composition and abundance will be altered (Low, 2008). Because the proposed temperature changes will occur relatively gradually, it should be noted that genetic diversity itself may assist in maintaining the current speciation, though this is much less likely for rare and threatened species. The report by Dunlop & Brown (*ibid*.) also notes that Australian species in general have a high resilience to disturbance and it is therefore quite possible that the Brisbane forests, woodlands and reserves will be able to more-or-less withstand the effects of climate change outlined in their report.

4.5.2 Overall changes to the macrofungi While there still remain too many unknown variables to allow firm predictions to be proposed, sufficient research exists to suggest that the proposed temperature alterations will still support the domination of Brisbane's forests and woodlands by species of eucalypt. Given this scenario, there is every reason to believe that suitable mutualistic partners will still be present for the ectomycorrhizal fungi, that parasitic macrofungi will still be able to attack suitable hosts and that litter-inhabiting macrofungal taxa will still be present, subject to the conditions discussed below. Whether or not the current diversity, relative distributions and abundances of these three groups remain the same or change is currently unpredictable and such information will only be procured by urgently implementing macrofungal biodiversity monitoring and research programs.

In many instances, rising temperatures will also modify the annual timing of fruiting body production. Recent reports document the alterations to fruiting body appearances of the macrofungi in Europe, where it is much simpler to obtain valid data because the relevant records have been maintained over a considerable number of decades (Krivtsov *et al.*, 2003). Several indications of the effects of climatic temperature changes have now been documented (Anon, 2007; Kauserud *et al.*, 2007) and they include:

- delays in the appearance of fruiting bodies of autumnal species because these species require the onset of cooler weather conditions for successful growth;

- earlier seasonal fruiting of the macrofungi in the more northerly parts of the range of the various macrofungal species;

- a shorter period of time in which fruiting bodies actually appear; and

- significant numbers of autumnal species are also fruiting in spring.

4.5.3 General reactions to temperature by the Brisbane macrofungi

Apart from the mangroves, Brisbane's forests, reserves and parklands are essentially dominated by eucalypts and it is highly probable that Brisbane's macrofungi will be reacting to higher temperatures in the same way as the macrofungal species of the northern hemisphere. Higher temperatures should mean earlier summer fruiting but this may also mean that fruiting will end sooner than at present, given that the effect of the higher temperatures may simply be to shift the whole fruiting period length to an earlier point in the season. Autumn fruiting of the mycorrhizal species that require lower temperatures as the “trigger” for sporocarp production, will be slightly delayed, appearing in the cooler month of June, rather than the traditional time of May. There is also the possibility that a number of the litter taxa with less rigorous habitat requirements will fruit more opportunistically, i.e. whenever moisture conditions permit. This adjustment may have some effects on the arthropod populations that require the macrofungal fruiting bodies as a food resource during their juvenile stages. Since it is expected that these shifts will be gradual, it is reasonable to suggest that the arthropods will be able to adapt to these altered conditions.

4.5.4 Higher temperatures and ectomycorrhizal macrofungi Warmer temperatures will impact on the macrofungi of the Brisbane region in several specific ways, presuming other factors (e.g. drought) allow normal functioning of the macrofungi to continue. Assuming survival of the Brisbane eucalypt woodlands and forests as outlined above, and that an appropriate moisture regime is present, increasing temperatures are predicted to produce increased rates of tree growth (Scurfield, 1961; Loveys *et al.*, 2002). Pregitzer *et al.* (2000) support this conclusion, but also warn that there remain considerable uncertainties remain, especially in relation to how deep-rooted trees will react to the temperature increases because soil temperatures will inevitably affect root growth rates. This in turn has implications for the mycorrhizal macrofungal taxa sharing mutualistic partnerships with the eucalypts. Where the microfungal (arbuscular) mycorrhizal species are concerned, increases in soil temperature enhance the rates of activity (Olsrud *et al.*, 2004), and there are also reports which indicate that similar increases in activity occur in the ectomycorrhizal species of macrofungi (Clemmensen *et al.*, 2006). If appropriate moisture levels are present, rising soil temperature should not affect mycorrhizal activities of the macrofungi. Their survival hinges on whether or not the host plant species can survive such temperature shifts, and how elevated CO_2 and temperatures will affect carbon re-allocation dynamics within host plants.

Of some concern is the effect that the rising temperature will have on fruiting body production in the hypogeal "truffle-like" fungi which function as a food resource for many native marsupials (see section 3.4.3). Mycophagous marsupials occur in northern Queensland (as well as throughout the remainder of Australia), illustrating the fact that various species of truffle-like fungi also occur in warmer climatic conditions. Given the natural ability of the eucalypts to tolerate considerable variation in annual temperatures and moisture availability, it seems reasonable to assume that the truffle-like fungi will also continue to survive, provided that their associated mycophagous vectors also endure the generally harsher conditions.

4.5.5 Higher temperatures and parasitic and litter macrofungi Warmer temperatures automatically mean longer periods of active growth for the fungi in general and therefore, if all other factors required for fungal growth are favourable, parasitic and litter recycling macrofungi will also benefit from warmer temperatures. An increase in parasitic macrofungal attacks can be expected in forest ecosystems accompanied by southward geographical shifts in species' distributions of naturally tropical/sub-tropical species, and accelerated activity of the litter, wood and general recycling taxa. This will apply to any and all of the parks, forests and reserves within the Brisbane region.

4.5.6 Higher temperatures and the mangrove macrofungi In the case of the mangrove woodlands, the predicted temperature rises should produce very little change in the medium-term because of the moderating effects of the sea. It is possible that parasitic macrofungi may be able to establish themselves more easily, but again this may be of low significance. During our sampling trips to Bayside Parklands (App.A, p5), Boondall Wetlands (App.A, p13) and Tinchi Tamba Wetlands (App. A, p49), no marked evidence of parasitic macrofungi was seen on the mangroves. The only fruiting bodies observed were those of wood decay polypores and they were infrequent. Nevertheless, it is also very possible that the rising temperatures may expose the mangrove woodlands to more successful attacks by macrofungal parasites. Careful monitoring of this situation will be required.

4.6 Rainfall Of the four climate change parameters cited (CSIRO, 2007; Dunlop & Brown, 2008), rainfall is the most critical in regulating the activities of the macrofungi because substrate moisture and sufficient levels of humidity seem to be extremely important if the macrofungi are to produce fruiting bodies. Dunlop & Brown (*ibid.*) also detail aspects of storms, snow and frost. (Whilst storms can be expected in the Brisbane region, snow does not occur and for the macrofungi, the minimal frequency and severity of frosts received in the Brisbane region can be considered irrelevant at this stage.) For the purposes of this report, the aspect of storms is subsumed into the general treatment of rainfall.

While rainfall is much harder to predict than other environmental variables, the models indicate that on average, Australia as a whole will become drier, however there will be seasonal and regional variations that will not correspond with general predictions (CSIRO, 2007). Although Dunlop & Brown (*ibid.*) suggest that parts of southern Queensland and northern New South Wales might become slightly wetter in summer and autumn, the CSIRO (2007) report places this in the less likely range of probabilities. For the purposes of this report, it is assumed that the Brisbane region will be at least slightly drier overall since this also agrees with the projections of both the CSIRO report and the Queensland report (Qld EPA, 2008). In summation, this report suggests that for Brisbane, summer and autumn rainfalls will vary from year to year, but the most probable outcome will be reduced summer total rainfalls compared with those of the previous decade, and the rainfall will occur over a shorter period of time. Furthermore, there will be longer periods of drier weather during winter. Storms are also likely to be more intense and will more often carry hail. Given that the increased temperatures noted in section 4.2.2 above will result in higher levels of evaporation, this will tend to reduce the amount of available ground-water remaining in the various Brisbane ecosystems.

4.6.1 Rainfall and the "summer" macrofungi If the above predictions prove correct, the authors believe that potentially there will be minimal deleterious effects on the macrofungal taxa that currently fruit in the summer season, whether mycorrhizal, parasitic or litter/wood recyclers. These taxa generally fruit in large "flushes" which usually last for one or two weeks. There is also evidence indicating that acute seasonal drought (for periods of approximately 3 months) does not permanently alter biomass and nitrogen dynamics in at least one northern hemisphere litter scenario (O'Neill *et al.*, 2003), and this tentatively supports the concept that Brisbane's litter-inhabiting macrofungal taxa will be able to survive the more severe winter droughts whether active, dormant, or as spores. Provided the summer and autumn rains are sufficient to sustain normal fruiting regimes and that sufficient ground-water persists to enable these macrofungi to begin accumulating resources for hyphal development and the next season's fruiting, the litter recycling macrofungi should survive the postulated climate changes. This in turn will continue to provide adequate food resources for the arthropod and gastropod populations. Nevertheless, these are hypothetical projections which need to be replaced with valid data as soon as practicable.

4.6.2 Rainfall and the "autumn" macrofungi Of more concern is the autumnal fruiting of the ectomycorrhizal macrofungi. If insufficient rainfall occurs, this may impact on fruiting of these taxa to the extent that while some mycelial growth may take place, the normal "flush" does not occur. Under these circumstances, spore dispersal will not take place and it is possible that some reduction of species abundance or even diversity could occur. Nevertheless, extended periods of "non-fruiting" of macrofungal ectomycorrhizal taxa are known to have occurred both in Australia and elsewhere apparently without threatening species survival. In the previous European republic of Yugoslavia, certain species of the ectomycorrhizal macrofungal genus *Cortinarius*, produced an effective fruiting season only once in 10◎15 years and a similar occurrence has been observed in the Blue Mountains region of New South Wales (Dr Alec Wood, *pers. comm*.). This suggests that the macrofungi themselves may be more durable than the casual observer may appreciate and urgent attention needs to be devoted to obtaining relevant data as the next logical step in gaining knowledge on the resilience of Brisbane's ectomycorrhizal macrofungi.

4.6.3 A summary on the macrofungi and rainfall

1. During dry weather, the ectomycorrhizal species retreat within the host roots and so are protected. There are no indications that this will not continue well into the future in the Brisbane region. Extended dry winter conditions, should they occur, will not affect the ectomycorrhizal taxa as long as their mycorrhizal partners survive.

2. The parasitic macrofungi should not be adversely affected by dry winter and spring periods since the mycelia will be sheltered within the hosts. These taxa are likely to be more active in the higher temperatures of the summer periods (see 4.5.5 above) and also will be active in suitable hosts during the winter-spring period assuming warmer conditions prevail. If the parasites are more virulent during the winter season, they may inflict more severe damage to their hosts or even eliminate them within much shorter timeframes, particularly if the hosts are concurrently subjected to high levels of drought-induced stress.

3. The litter/wood recycling taxa should fruit as usual in the summer/autumn period. Sufficient rainfall and humidity are the controlling factors and provided there is at least the projected rainfall for this region (CSIRO, 2007), then there should be little if any effects on this group of taxa during the summer period. For the remainder of the year, opportunistic taxa able to take instant advantage of any rainfall events will potentially commence to fruit and therefore may become more abundant in the region.

4. There should be little, if any, effect on the hypogeal mycorrhizal taxa which are utilised as a food resource by the native mammal population.

4.7 Sea levels and the macrofungi The Department of Climate Change Assessment (Dunlop & Brown, 2008) predicts that sealevels will increase by 18◎59 cm by 2100. It is feasible that this rise will affect several parks and reserves in the Brisbane region that contain very low mangrove and salt-marsh habitats on their water-bound peripheries. Those likely to be affected include: Brisbane Botanic Gardens (City) (App. A, p18); Boondall Wetlands (App. A, p13); Tinchi Tamba Wetlands (App. A, p49); and Bayside Parklands (App. A, p5). When applied to the Inundation Maps included within the Climate Change and Energy Taskforce Final Report (2007) – which were based on a 30cm sea level rise and storm tide of up to 6.76m - these figures, in and of themselves, show little resultant impact on the Brisbane region. This situation would, however, be severely compromised in the event of severe storms or cyclones crossing the coast in the vicinity. Considering that the largest storm surge tide measured in Australia to-date was 14.6m near Cooktown in 1899 (Lossee et al, 2007), the increases predicted by Dunlop & Brown (*ibid*) will produce considerable additional impacts during natural climatic catastrophes.

As already noted, short of undertaking extreme measures such as constructing complex levee banks, there is little that can be done to prevent permanent inundation of the present mangrove thickets and woodlands, and, depending on their height above sea level, various parts of the associated marshes and grasslands will become subject to tidal inundations. The mangroves will gradually disappear from permanently inundated areas, but should migrate into the newly established tidal zone. Since the mangroves will still persist along the littoral fringe, and new grasslands will undoubtedly establish immediately abutting this zone, there should be a minimal adverse impact on macrofungi which are associated with the mangrove areas. The transition period may, in fact, prove advantageous to transient wood-rotting taxa, as the quantity of dead or susceptible timber becomes temporarily more plentiful.

4.8 Fire "The incidence and severity of forest fires are linked to the interaction between climate, fuel and topography." (Nitschke & Innes, 2008). This one sentence summarises the entire problem of fire management in the Brisbane region. Nitschke & Innes also state that a warmer and drier climate will lead to drier forest fuels (which in turn increases the chances of fire ignition and dissemination) and that a warmer climate would extend the length of the fire-hazard season. Finally, they conclude that prevalence of such conditions will increase the risks faced by ecosystems and their biodiversity under climate change and will increase the costs and difficulties of achieving sustainable forest management. Similar conclusions on the risks of fire to Brisbane's biodiversity have also been reached by Low (2008).

4.8.1 Climate change and fire regimes The NRMMC Report (2004) notes that climate change will have an effect on fire regimes, but Dunlop & Brown (2008) indicate that the most likely climate changes will lead to an increase in fire frequency. Increased CO_2 levels will potentially lead to increased litter deposition and consequently fuel availability in the eucalypt forests will also be increased. As noted in section 4.4 above, the litter deposited will be lower in nutrient concentrations and may not be as readily decomposed as higher quality litter. Therefore there may be larger amounts of litter available as fuel for future fires and their intensities and coverage may increase. This in turn has implications for the biodiversity of the higher plants and animals of the area and also for the macrofungi.

The report by Low (2007) also stressed the extreme importance of dealing with the expected increase and severity of bushfires in the Brisbane region. Low listed a warmer climate, more droughts, less winter/spring rainfall, longer periods of low humidity, increased biomass and smaller "windows of opportunity" for prescribed burns as the principal reasons for his concern. Other areas of concern in the Low report involve the effects an increased fire regime could have on Brisbane's entire flora/fauna biodiversity, the effects of flammable weeds, the entire loss of some Brisbane ecosystems (rainforest and riparian forest) and the transformation of open forest to grassy woodlands. Low (2008) expanded on his earlier report by describing threats to specific animal and plant species in the Brisbane region.

4.8.2 Fire and its effects on macrofungi Given the above concerns, and the fact that eucalypt litter is naturally quite combustible, the effects of fire under climate change are a considerable threat to the survival of the macrofungi of the Brisbane region. Robinson & Tunsell (2007) recorded the appearance of macrofungi on burnt and unburnt areas of karri forest in Western Australia over a five year period. No attempt has yet been made to analyse this data in terms of biodiversity or species abundance, however a cursory inspection of their lists shows that at least some litter and dead wood inhabiting species had not yet reappeared in the burnt areas after five years. Conversely, successful repopulation of the burnt areas had apparently taken place quite readily by many other taxa. Similar results seem to occur with the mycorrhizal taxa. Young (1999) did not analyse similar sets of data from the Mt Glorious area of South-East Queensland, but did indicate that in the absence of any further disturbance (such as that produced by cattle), then macrofungal recolonisation of a burnt area of forest could occur within as little as a 2◎4 year period. It must be stressed, that sampling of the macrofungi did not supply conclusive evidence as to whether highly sensitive taxa had returned to the burnt site.

Currently, there is no extensive data available for the Brisbane region regarding the survival of macrofungi under the impacts of either (or both) climate change and fire. Given that the Brisbane region is not an isolated habitat as far as the fungi are concerned, areas damaged by fire could be re-inoculated from undamaged areas over several years by wind-borne spores or by spores carried in by various human or animal activities, provided that elevated CO_2 levels and temperatures, together with with reduced soil moisture, do not adversely impact the macrofungi's physiological capacity to re-establish. At the present time, ongoing uncertainties pertaining to climate change impacts on ecosystems make predictive attempts difficult if not impossible, however, if the higher plant ecosystems survive the effects of fire in a more-or-less intact state, then so too should most of the macrofungi. Litter and wood-inhabiting macrofungi will re-establish over a period of time, however the data available so far suggests that for some species, this may take more than five years. The degree to which the litter layer is either destroyed, or replenished by the ensuing litter mass generated in the canopy by the fire itself (and the associated nutrient quality of that litter), will also impact upon the rate at which saprophytic macrofungi are able to return to the site. Mycorrhizal taxa are more or less shielded from all but the worst of fires and provided the fire intensity is such that the soil is not sterilised around the root zones (which in any case would suggest root and host death) they will survive intact in the host roots. This is also suggested by the data of Robinson & Tunsell (2007). Parasitic taxa will survive for the same reason: if the infected host survives, so will they. Additionally, spores of the parasitic species will re-inoculate from the surrounding regions.

4.8.3 Fire mitigation and sensitive areas in the Brisbane region Low (2007) has suggested a number of ways of mitigating fire risk in the Brisbane reserves (including the use of regular fuel reduction burning), however he also points out that this carries the risk of considerable harm to the ecology of the relevant forests or woodlands simply because it: damages the lower plants; destroys litter inhabitants that cannot move out of the way of the fire; destroys the denser habitats that are required by a percentage of the Brisbane fauna; and finally, temperatures generated during the fire can have negative impacts on characteristics of the soils underlying the system, especially those of moisture and microbial levels. As Low correctly points out, the challenge is to mitigate fire risks by using fire management protocols designed to prevent the random occurrence of high intensity wildfires, whilst concurrently selecting seasonal conditions that result in minimal damage to the relevant ecosystems.

The importance of fire mitigation in preserving the macrofungi cannot be over-emphasised, however, as has been noted with other variables such as temperature (section 4.5.3), if the present forest, park or reserve systems are preserved in perpetuity, and expanded upon in order to achieve potentially more stable results, then the resident macrofungi should likewise persist . The results of Young (1999) and Robinson & Tunsell (2007) both suggest that single fires do little damage to macrofungal biodiversity over extended periods. This notion is supported by the gamut of pre-existing literature on Australian sclerophyllous environments, and is particularly relevant to such habitats in the Brisbane region: they are highly resistant to occasional fires (even high intensity wildfires) and regenerate completely given sufficient time and the appropriate conditions. Virtually all the forests, parks and woodlands surveyed in the sample given in Appendix A will fall into this category. Certain specialized niches within these parks, such as fern gullies, or those containing relict rainforest species or vine thickets, will be especially sensitive to fire (Low 2007), and it is imperative that these be carefully managed and assessed under any fire mitigation system.

The less intense the fire, the less the damage done to ecosystem components and therefore, theoretically, the shorter the period required for complete regeneration. The remaining difficulty lies in estimation of the time interval that should be allowed for forest regeneration before the next burning takes place. Many fire control regimes assume ideal regeneration conditions soon after a management-induced fire however under the possible future climatic conditions, this may not occur for some time. This in turn means that any controlled fire will produce some risks to the relevant ecosystem, and the fire management protocols must have an ongoing monitoring system in place to ensure that regeneration has taken place.

There is no data on the Australian macrofungi (to the knowledge of the authors) that can support any management options, however it is likely that rotational and mosaic burning practices are the best way to approach the problem. Furthermore, the periods of time between burns should be sufficiently long as to allow optimal regeneration of the ecosystem whilst remaining cognizant of the need to prevent litter buildup from becoming so severe that an intense fire can eventuate. This would suggest time-frames of between five and ten years as the best option. Such a program will require extremely careful fire management protocols designed to retain biodiversity at all levels, and as Low (2007) also remarks, in this respect, fire management will continue to provide a challenge for the Brisbane City Council.

4.9 Weeds There are several reports which assess the effects of climate change on weeds (e.g. Kriticos *et al.*, 2000; NRMMC, 2006) and which suggest that the warmer temperatures produced by climate change will potentially allow tropical weed species to extend their ranges further southward. Whether any (and which) of these species will reach the Brisbane area is uncertain. Moreover, it is difficult to predict how climate change will affect the weeds that are already present in the Brisbane region. Low (2007) indicates that the present weed species should become far more aggressive in their activities and if native plant species are impeded by drought or temperature rises then exotic weed invasions become a higher probability. A summary on weeds in the Brisbane parks, forests and reserves is included in Appendix A.

4.9.1 Weeds and the macrofungi There is no available Australian data describing past or present effects of weeds on the macrofungi, nor is there any data which will allow prediction of the possible impacts climate change will generate between weeds and the macrofungi from either an Australian perspective, or more specifically, in relation to the Brisbane region. Nevertheless, it is difficult to see how the present weed infestations will markedly reduce either the macrofungal biodiversity or their occurrence in any of the Brisbane reserves considering the status of current weed distributions and associated management practices. Unless a weed taxon completely assumes dominance in any particular habitat, the native trees will remain and in turn, their mycorrhizal associates should also survive. Parasitic species will also be unaffected in the event of host survival.

The effects on the native litter recycling macrofungi, however, may be of more importance should the indigenous understory plant species be replaced with weeds. With the exceptions of: first, the Mt. Coot-tha Forest (App. A., p. 43) which has very large areas of exotic grass infestation together with slopes wholly covered by *Lantana camara*; second, areas of the Boondall Wetlands (App. A, p.13); and third, some fern gullies and vine thickets and along the banks of certain creeks and streams (e.g. Brisbane Koala Bushlands [App. A., p. 24]; Chermside Hills Reserves [App. A., p. 30]), our observations suggest that weed infestations are generally restricted to quite small and controllable areas in the parks and reserves of the Brisbane region. In some cases, riparian sites which would otherwise appear to be obvious candidates for weed infestation have so far escaped significant invasion despite occasioning considerable human pedestrian traffic (e.g. Mimosa Creek at Toohey Forest [App. A, p.50]). It would be of considerable interest to ascertain why this relative absence of weeds exists in these areas and whether there is any possibility of applying the knowledge acquired from investigating this issue to other locations.

4.10 Chapter Summary

4.10.1 *Climate Change, Modelling and the Brisbane Region*

- There are no previously published documents specifically describing how the Australian macrofungi are reacting to, or will react to, future climate changes.

- There is considerable room for error if models developed for climatic change in overseas ecosystems are applied to the Australian context.

- The extensive databases that would allow accurate modelling of Australian ecosystems and climate change, are either non-existent or have too many gaps in the participant data to be fully useful. Modelling of the responses of Australian macrofungi remains extremely hypothetical.

- The Brisbane region (and South-East Queensland) is an area that is peculiarly sensitive to climate changes because it represents an "ecotone" between tropical and temperate biosystems.

4.10.2 ***Rising Atmospheric Carbon Dioxide levels and the macrofungi***

- Ectomycorrhizal species will probably not be affected unless the current symbiotic eucalypt or mammalian species disappear.

- Parasitic species are likely to become more aggressive, with associated increase in instances of host destruction or death.

- Litter and wood recycling species should only be minimally affected.

4.10.3 ***Rising Temperatures and the macrofungi***

- The summer fruiting macrofungal species will probably appear earlier in the annual cycle and there is likely to be a shorter time period over which the fruiting bodies appear. Autumnal species which require cooler climatic conditions will delay their appearance until suitable weather conditions prevail.

- Ectomycorrhizal macrofungi should not be affected if their mutual partners are also able to withstand the higher temperatures.

- Activity of parasitic, litter and wood recycling species will probably all increase, whether in terrestrial or littoral systems.

4.10.4 ***Rainfall and the macrofungi***

- The expected reductions in rainfall will probably not affect the summer fruiting macrofungi markedly, but may impact on those species which fruit in the autumn periods, which are now predicted to be much drier.

- Ectomycorrhizal macrofungi should survive as long as the mutual partners survive.

- Parasitic macrofungi may possibly produce more damage if drought stress weakens the host's ability to resist parasitic attacks.

- The species composition of litter and wood recycling taxa may be modified to the extent that those taxa that can take rapid advantage of any winter rainfall (opportunistic) will be selectively enhanced for survival compared with those species that do not possess such a rapid ability to react. This may lead to some species becoming increasingly rare or locally extinct, thus imposing a loss of biodiversity on Brisbane's ecosystems.

4.10.5 *Sea levels and the macrofungi*

- Rising sea levels should have minimal long term effect on the mangrove macrofungi. Since the littoral mangrove swamps will re-establish in the new tidal zones over a period of time, it is probable that any macrofungi associated with the mangroves will also migrate with the woodlands and re-establish.

4.10.6 *Fire*

- Forest/woodland fires will increase in frequency, coverage and intensity in the absence of very carefully constructed, site-appropriate management policies.

- Low intensity fires implemented in a controlled, rotational 5◎10 year cycle should allow for management without detriment to the macrofungi of any of the eucalypt habitats in the Brisbane region.

- Highly sensitive areas such as vine thickets, fern gullies and rainforest remnants will require extremely careful management to minimise fire damage and it is possible that total fire prevention is the best policy for these locations.

4.10.7 ***Weeds***

- A summary of the weed status as provided by the sample survey is found in Appendix A which is attached to this document.

- Unless weeds completely out compete the native species in any given area, it is unlikely that they will impact adversely upon the indigenous macrofungi in the eucalypt woodlands and forests.

- Litter and wood recycling macrofungi in the vicinity of fern gullies, vine thickets and relict rainforest may be at some risk due to weed infestations in these locations. They are more favourable environments for weed growth due to the increased availability of water and nutrients, higher relative humidity and lower isolation; the same conditions which promote the proliferation of saprotrophic macrofungi.

5. Macrofungi: Importance to Brisbane; Conservation Issues & Key Proposals

5.1 *Summary of macrofungal importance to Brisbane's parks, reserves and forests*

- **Mycorrhiza** The macrofungi form mutualistic partnerships with the eucalypts which dominate many of Australia's forests and woodlands. Most of these trees and shrubs would either die or exist in stunted and weakened forms if the macrofungal partners were either absent or were unable to perform their present functions. The result would be the loss of most of Brisbane's forests and woodlands, and their constituent fauna.

- **Litter** A considerable proportion of litter and wood recycling is completed by the macrofungi present in Brisbane's ecosystems. Without their presence, litter buildup and fire hazards would increase, and soil fertility would inherently diminish. There would also be negative effects on biotic elements of the soil and litter, and biodiversity would almost certainly decrease, particularly in response to fires.

- **Food resources** The ectomycorrhizal macrofungi provide a vital food resource for small native mammals in Brisbane's reserve system. At least one local and endangered mammalian species (the long-nosed potaroo) cannot survive without these underground macrofungi. The macrofungi also provide enormous food resources for insects and other invertebrates, as well as some reptiles, and the absence of this food resource would definitely affect species abundance and distributions of the local fauna.

- **Parasitism** The parasitic macrofungi serve a natural, 'low intensity' role in Brisbane's bushlands, a natural process which facilitates removal of old and weakened plants or trees from the ecosystem, and also provides additional food resources for various members of the local fauna.

- **Bioindicators** The macrofungi are considered to be extremely useful as bioindicators of overall ecosystem health, pollution, heavy metal presence and climate change. At least some knowledge of the present composition of the macrofungal species of Brisbane's parks and reserves would allow better-informed assessments of all the above problem areas.

5.2 ***Protecting and conserving the macrofungi*** Given the "hidden nature" of the macrofungal organism (Lilleskov & Bruns, 2001), it is virtually impossible to conserve or protect an individual macrofungal species in the same way that a mammal or plant species can be conserved or protected. Conservation and protection of the macrofungi can be effectively accomplished by conserving and protecting the habitats in which they are known to exist, however there are numerous ways in which this action can be enhanced and coordinated. A guide on conservation of macrofungi (Senn-Irlet *et al.*, 2007) was prepared by the European Mycological Association (as part of the European Council for Conservation of Fungi) and presented to the Directorate of Culture and Cultural and Natural Heritage in the Council of Europe (Strasburg). Its key objectives were designed for application at a national level, and as such they are all directly applicable to the Brisbane region. All of these key objectives are accompanied by very exhaustive lists of actions designed to produce a successful outcome in each key objective. The key objectives (with minor modification to remove European references) are:

1. Understand and document fungal biodiversity.
2. Conserve fungal biodiversity.

3. Use the fungi in a sustainable way.
4. Promote education and awareness of fungal biodiversity.
5. Build a capacity for fungal conservation.

While some of these objectives and actions are more relevant than others to Brisbane's requirements, the proposals and actions of the European guide should nevertheless be taken into consideration in any future planning for conservation and protection of Brisbane's macrofungi. The key proposals presented below were mostly developed independently from those of the above document but agree with them in many aspects.

It is worth noting that on at least three separate and distinct occasions in its key objective explanatory notes, the European conservation guide emphasizes the recommendation that the participation of at least some highly trained and competent mycologists is essential to the successful outcome of any attempts to ensure effective conservation and protection of the macrofungi.

5.3 *Key Proposals*

5.3.1 Fire hazard reduction

There must be an extensive and monitored plan for carefully regulated, rotational mosaic burning of all of Brisbane's reserves that contain forest or woodland. No reserve should ever be burnt in its entirety on any single occasion. The most suitable rotation period for macrofungi is suggested as being somewhere between five and ten years since this will allow litter taxa to return but will not allow litter to build up to the point where intense and uncontrolled fires become feasible.

Designing and implementing an effective fire control protocol is probably one of the most difficult issues for the Council's administrative program. Many fire reduction strategies automatically assume normal regeneration will take place after the event, but under the predicted climate changes, it is likely that regeneration will be seriously impeded by less than perfect weather conditions that may follow. For the macrofungi in particular, autumn species may be fruiting at precisely the most desirable times for fire hazard reduction by burning and this will need careful "on-the-spot" monitoring to assess exactly what is occurring in the various reserves.

5.3.2 Weed control

The relevant proposals of the Low Report (2007) are supported in full.

5.3.3 Monitoring role

Given that the macrofungi form one of the most sensitive tools for assessing ecosystem change that is available, the following methods are proposed as strategies that could be used by the Brisbane City Council or other relevant bodies to collect the data for use in such monitoring:

i. **Macrofungal website** Create or support a macrofungal website. This could be used to encourage community involvement in the collection of information on the macrofungi of South-East Queensland.

ii. **QFungi database** Support the commencement of a databased reporting system on the macrofungal website (QFungi) with the aim of encouraging local naturalists, enthusiasts, etc. to communicate sightings of various target species to the website administrators. This in turn provides data which can be analysed to assess whether taxa are decreasing or increasing their ranges or altering their fruiting periods. Data from this project can be shared with the Fungimap project in Victoria and it is expected that this will be a two-way sharing relationship.

5.3.4 Publicity and organisational roles

The lack of materials and resources specifically designed to provide basic information on the Brisbane macrofungi to members of the community (especially school children) remains the largest problem. The web site as noted above (5.3.3.i), would assist considerably in disseminating information, however three additional methods of improving knowledge of the macrofungi in the wider community are suggested:

i. **Book production** Support the production of a book (field guide) describing the roles of macrofungi in Brisbane's forests and reserves together with representative species that are also relevant to the QFungi project. Inclusion of at least some of the toxic species of South-East Queensland, would make this resource of considerable benefit to the medical profession as well. This action would raise the level of public consciousness about these organisms especially with respect to their permanent (if hidden) nature and their immensely important roles in ecosystems. This book could be part of the series already in production.

ii. **Organisational support** Support the activities of any relevant mycological or natural history organisations/societies that are attempting to advance knowledge of Brisbane's macrofungi. It will be essential to establish an associated information network for the various groups and an established web-site (5.3.3.i) could be part of this process. Training sessions in how to collect, record and preserve macrofungi would automatically follow .

iii. **Educational awareness** Consideration should be given to the production of interpretive booklets and guided walks for the various parks and forests. Information on the wide range of fresh and dried edible fungi now available through commercial outlets could also be considered. Public support and awareness are the keys to successful fungal conservation because without this aspect, macrofungal conservation is impossible either to fund adequately or justify. This educational aspect correlates with the production of the field guide mentioned in item (i) above. If the council's programs can reach school children at any level, considerable benefit to the conservation objectives will be obtained.

5.3.5 Support for long-term macrofungal research

In order to produce meaningful data, an initial project should be planned which would have a lifetime of at least 5—10 years, but preferably be ongoing for a minimum of two decades.

Any project developed with a focus on Brisbane's macrofungi will be documenting an almost completely unrecorded component of the biota. Provided the appropriate web-site and support networks are set up as described in 5.3.3, the project should neither be excessively difficult or costly. An additional advantage is that the project will contribute directly to the knowledge of the biodiversity of the macrofungi of Queensland as a whole. The unique composition of Queensland's macrofungi, and those in South-East Queensland and the Brisbane area in particular, is contributing to the fact that overseas mycologists are now viewing this region with enormous interest.

5.3.6 Park and reserve aggregation

Where possible, amalgamate existing isolated parks and reserves into single, larger units, through a program of interjacent property acquisition, such that a large "ecosystem biomass" is produced. Such amalgamations would have impacts on local government land management decision-making processes as well as broad policy and there will need to be targeted research on how best to apply such procedures.

Larger reserves have a greater potential for preserving the habitats they contain because they have a better capacity to buffer themselves against disturbances and threats. The best examples of such disjunct reserves include the Chermside Hills reserves and the Koala Bushlands. Whilst corridors are an improvement, action still needs to be taken to form large single tracts of forest or woodland from isolated habitat "islands" by resuming intermediate lands. In some cases this may already be impractical, but it is recommended that it be implemented where possible. Larger ecosystems allow for forests/woodlands to conserve their structures more readily, and provide more substantial connectivity between specialist niches that may occur sporadically throughout the region. Mt Coot-tha/Brisbane Forest Park (App. A, p.43) and Karawatha Forest (App. A, p.37) are excellent examples of large-scale forests which should more readily withstand the effects of climate change.

5.3.7 Support for management of forests and woodlands held by private landowners

It is recommended that management support be provided to private landholders to better assist them to conserve their holdings and the macrofungi they contain.

This study concentrated on public lands managed by the Brisbane City Council, however large amounts of forest and woodland are held privately throughout the Brisbane region. All of the concepts outlined in Sections 2, 3 & 4 of this document will apply equally to any forest/woodland in the Brisbane region and the key proposals put forward in the preceding parts of this section will largely apply to these private holdings. The availability of publicity and educational awareness materials will be of immense value to these people.

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Appendix A

Forest, Reserve and Park Summary

Explanatory Notes

This summary contains the reports made on a representative sample comprising ten of the forests, reserves and parks contained within the boundaries of the City of Brisbane. A map showing the city boundary and the locations of each of these areas is to be found immediately after these explanatory notes (Figure 1). The following locations were visited during the interval April-May 2008:

These summary reports do not specifically indicate the presence or absence of macrofungal species at the various locations. The summaries are intended to provide a synopsis of the various types of habitat available at the sites visited together with indications of the likely stresses that might be encountered due to climate change. The purpose and time line of the report (as well as the prevailing weather conditions under which the surveys were compiled) meant that a checklist of the taxa present at each site was both irrelevant and impossible. The summer rains ended in late March 2008 and although some macrofungal fruiting bodies were still evident in Karawatha Forest during the start of the data collection in early April, the very dry weather that then followed throughout the rest of April and May prevented any further emergence of fruiting bodies.

It is important to note that considerable emphasis was placed on the type of vegetation found at each location as this gives a general, but reasonably accurate, picture of the types of macrofungal taxa likely to be found at the various sites. Grassland will provide a good habitat for certain taxa, however the mulched beds in gardens at the various locations are also an extremely favourable habitat for litter inhabiting species, especially where the litter occurs under dense shrub cover.

Eucalypt forests and woodlands provide excellent habitats for ectomycorrhizal species, especially where the trees occur on poor, sandy soils because these habitats cannot be successfully colonized by the trees without their fungal partners. Of immense interest too are the casuarina thickets or woodlands because casuarinas are known to support rich ectomycorrhizal diversity. Observations seem to indicate that mixed eucalypt/casuarina woodlands or forests are particularly rich in ectomycorrhizal species. The summaries also consider the state of the forest/woodland floor with respect to litter and logs. Litter depth gives some rough indications of fire frequencies but may also provide some indications of possible tree stress due to drought: leaf shedding can produce high levels of litter. Under normal conditions, a thick litter layer can assist in naturally mulching the forest floor (with positive effects on soil moisture, temperature and microbial diversity) and it also provides an excellent habitat for the litter-inhabiting macrofungi. Logs on the forest/woodland floor are also very important for a number of macrofungi engaged in the rotting of timber. It is essential that at least some logs and branches of all diameters survive other environmental factors (such as fire) because fungal species can be very "selective" as regards the size of the branch or log colonized and several taxa are to be found only on small branches less than a centimeter in diameter, while others are commonly to be found on small logs up to 10cm diameter. A variety of logs from various woodland/forest species is also desirable because some macrofungal taxa exhibit what can best be called "preferences" as regards wood substrates in that they only occur on certain types of wood. Although it does not occur in the Brisbane area, an example of this "preference" is shown by the species *Tyromyces pulcherrima* which only occurs on the heart wood of Antarctic or Southern Beech (*Nothofagus* spp.).

Each summary has a small number of images attached to best display the salient features of the park or reserve which might be affected under climate change. Where human impact is believed to be pertinent, this is also included. Weed species are considered to be relevant where they can compromise the local flora and if naturalised species are already present, their type and abundance is discussed briefly.

Weed Summary

The sample survey as contained in this appendix provided the following information on the present weed situation:

i. Weeds tend to concentrate in areas of high fertility and water availability and therefore major weed infestations are usually found along the banks of creeks and streams (e.g. Chermside Hills Reserve, p30; Mt Coot-tha Forest, p43; Brisbane Koala Bushlands, p24).

ii. Exotic grasses have invaded some of the parks (e.g. Karawatha Forest, p37; Mt Coot-tha Forest, p43) and these invasions are not only a fire hazard, they also choke out the native underlying shrub layer.

iii. *Lantana camara* is established to some extent in some of the parks (Mt Coot-tha Forest, p43; Chermside Hills Reserves, p30) and can even form entire slopes of infestation. Eradication of this weed is a "two edged sword" because although it is non-native, it does provide an extensive and very useful habitat for those birds and mammals of the Brisbane area that require a dense undergrowth for survival. Curiously, it does not seem to be able to invade the drier forest/woodland parks such as Karawatha (p37) and Toohey Forest (p52) and only occasional stunted plants occur.

iv. Weeds (especially vine species) are severe problems in parts of Mt Coot-tha forest (p41) where their invasion of moist gullies and native vine thickets has virtually destroyed the original vegetational structures.

v. At least some parts of the Boondall Wetlands (p13) are virtually a "weed conservation area" in that the infestations are considerable. Part of the problem may be that the whole area has an underlying water table which benefits weed infestations. However the influx of weed species is probably due to pedestrian traffic, wind bourne seeds and flying fox excreta.

vi. The perimeters of all of the parks, reserves and forests are under constant threat particularly where they abut onto suburban housing. These are the locations where weed infestation is very common due to both garden escapes and deliberate dumping of garden refuse.

vii. The policy of permitting horse movement in these reserves raises the risk of infestation from the only partially digested dung deposits of the horses (Mt Coot-tha Forest, p43; Brisbane Koala Bushlands, p24). These often carry viable seeds and can spread weeds in hitherto uninfested areas.

viii. Some weeds (eg. *Ochna* sp., *Bryophyllum* sp., *Asparagus* sp., Chinese elm) pose considerable invasion threats if they manage to spread widely and choke out native species.

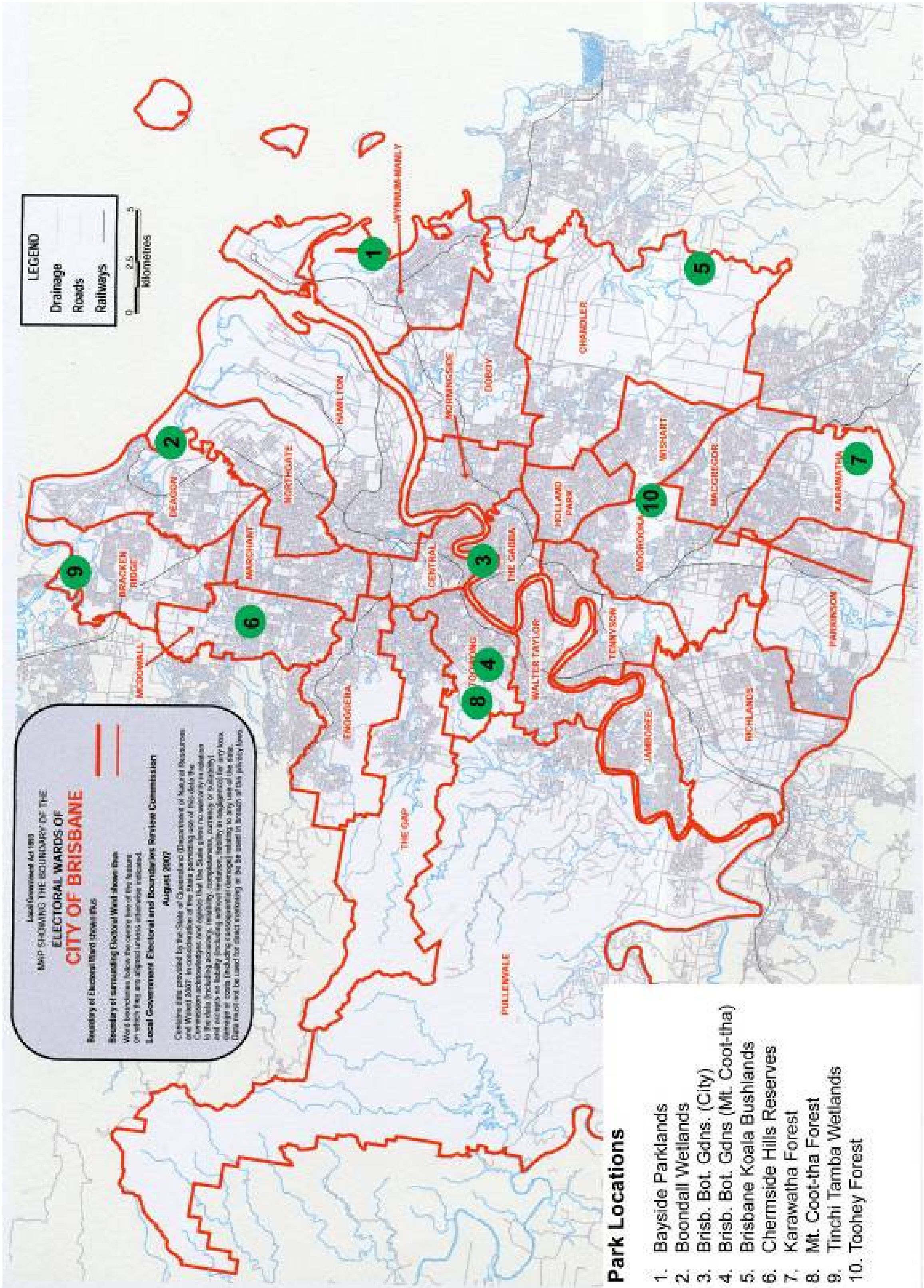
LEGEND
Drainage
Roads
Railways
kilometres
MAP SHOWING THE BOUNDARY OF THE
ELECTORAL WARDS OF
CITY OF BRISBANE
Local Government Electoral and Boundaries Review Commission
August 2007
HAMILTON
CHANDLER
DOBOY
MORNINGSIDE
DEAGON
NORTHGATE
MARCHANT
BRACKEN RIDGE
CENTRAL
THE GABBA
HOLLAND PARK
WISHART
MACGREGOR
KARAWATHA
MOOROOKA
TENNYSON
WALTER TAYLOR
ENOGGERA
THE GAP
PULLENVALE
JAMBOREE
RICHLANDS
PARKINSON
MCDOWALL
Park Locations
1. Bayside Parklands
2. Boondall Wetlands
3. Brisb. Bot. Gdns. (City)
4. Brisb. Bot. Gdns (Mt. Coot-tha)
5. Brisbane Koala Bushlands
6. Chermside Hills Reserves
7. Karawatha Forest
8. Mt. Coot-tha Forest
9. Tinchi Tamba Wetlands
10. Toohey Forest

Figure 1. City of Brisbane boundaries and the site locations visited. (Map obtained from the web site: http://www.abc.net.au/elections/brisbane/2008/guide/maps/lm.pdf)

Bayside Parklands

Size: 550 Ha. **Location**: 27° 28'S; 153° 11'E (Ransome Road Reserve [27 Ha])
27° 30'S; 153° 10'E (Tingalpa Creek Reserve [88 Ha]).
27° 25'S; 153° 10'E (Wynnum Conserv. Site Park [27 Ha]).

Vegetation

These parklands stretch for 16km from Whyte Island in the north to Lota and Tingalpa Creek in the south. Three of the constituent reserves were investigated. Ransome Road Reserve at the end of Chelsea Road borders a mangrove inlet, however the remainder consists of eucalypt/casuarina woodland/forest (Plate 1) with sporadic paperbark (*Melaleuca*) elements. The woodland/forest floor seems remarkably lacking in many taxa but there appear to be abundant native grasses and ample litter. Apart from the mangroves and the associated saltpan/marsh areas (Plate 3), some of the indigenous taxa seen in various parts of the Ransome Road section include species of: *Banksia*, *Lomandra*, *Melaleuca*, *Lophostemon*, *Alphitonia*, *Xanthorrhoea*, *Acacia* and *Pteridium*. The forest/woodland seems extremely healthy and there was no evidence of any damage to the various elements (Plate 4). Logs are left where they have fallen in a completely natural state in all of these Reserves, and are only "removed when fire occurs, or if they block an access path.

The Tingalpa Creek Reserve is more or less similar in some areas (Plate 5), however there are more paperbarks in some areas, tree-form coastal banksias appear, and there are areas of true eucalypt forest based on "scribbly gum" (Plate 7). At other parts, the habitats grade into a "wallum" component (Plate 6) based on the very sandy soils and the low shrub/heath like vegetation suggested by this floristic type: *Pimelea*, *Xanthorrhoea*, *Banksia* spp., *Leptospermum*, and various forms of sedges, etc.. Litter is abundant and thick and the "stags" (clusters of old dead trees that occur naturally) first noted in the Boondall Wetlands reserves are also present here. The Wynnum Conservation Park represents an entirely different type of vegetation and is essentially an area of mangrove swamps (*Avicennia marina*) (Plate 8) and coastal grasslands with some associated saltmarsh/mudflats. There is an on-going project to replace the bordering mangrove vegetation and such trees as eucalypts and casuarinas (as well as smaller salt tolerant native shrubs) are now being planted (Plate 9).

The Wynnum North Mangrove Boardwalk is bounded by Moreton Bay on the seaward side and the recreational grasslands of Elanora Park on the southern side. To the west lies the Caltex Oil Refinery and the Sewage Treatment Plant. The other two Reserves are bounded by bitumen roads and the railway line on their eastern sides.

Aspect and Features

The two eucalypt/casuarina woodland/forest Reserves are essentially flat, a metre or so above sea level and composed largely of coastal sands, however the northern mangrove area is based on deposited mud and is subject to tidal inundation.

Walking Paths

The Ransome Road section has a bitumen surface walking/cycling track loop allowing access to the much of the park. As in other locations surveyed, the bitumen paths encourage walkers/cyclists to stay on these prepared surfaces simply because the walking is so much easier. Other benefits are that soil compaction, weed seed dispersal and soil pathogen spread is minimized. The loop track at first runs beside the mangrove inlet and also allows access to very unusual "dwarf *Melaleuca*" thickets (Plate 2) it then proceeds in a long loop through the woodland/forest to return to the entrance. There was virtually no evidence of any human movement off the paths either in this section or the following section of the park series. Conversely, the path in the Tingalpa Creek section has been left in its natural state and is soft sand. Horses are permitted in this section (dung deposits) and there was physical evidence that motorised vehicles (probably 4WD) are using these tracks. The soft track surfaces are undoubtedly intended to cause minimal stress to horses movements, and the flat terrain together with the high permeability of the soil means that erosion problems are not considered of appreciable concern. The Wynnum Conservation Park section is reached via a pedestrian-only raised board-walk which proceeds for a considerable distance through the swamp. Extreme care has been taken with its construction so as to disturb or remove any mangroves as little as possible. It is virtually impossible for visitors to leave this prepared pathway.

Fire

Fire is irrelevant in the Wynnum Conservation Site section apart from the fact that the bordering regeneration areas might be damaged by fires, but this is considered to be a probable rare event given that these regeneration areas are protected by extensive, regularly maintained, artificial grasslands which are used for sporting events. Fire appears to be a very occasional event in the remaining two reserves, Ransome Road and Tingalpa Creek. There was some evidence of past fires indicated by old scorch and burn marks on the trunks of medium to large trees, but there was no evidence that any fire had moved through these two reserves within the last 5 years.

Weeds

The **Chelsea Road** section has a number of weeds along its margins, especially near the mangrove swamp borders: *Melia azedarach* (white cedar), *Bryophyllum* sp.(mother-of-millions), *Asparagus* sp., *Lantana camara*, *Passiflora* sp., *Euphorbia*, etc. These weeds do not seem to be penetrating the core of the reserve and remain more or less tied to the margins. Weeds were not noted as a problem in the section of the **Tingalpa Creek** park that was surveyed. In the Wynnum Conservation Site section, there were no weed incursions into the "mangroves proper", however a small sheltered gully providing drainage from the bordering grasslands and lined with trees to form a small gallery woodland displayed numerous weed species such as *Hibiscus* sp., *Celtis sinensis* (Chinese Elm), *Ricinus communis* (Castor Oil plant), *Cestrum parqui* (Green Cestrum) and *Solanum* sp. These weed taxa are obviously taking advantage of the better water conditions and soil fertility leachings along the water course.

Sensitivity to Climate Change

It is extremely difficult to indicate precisely how climate change might affect either of the two non-tidal reserves surveyed. Each is composed of drought tolerant species and it is reasonable to suggest that provided the dominant taxa (eucalypts, paperbarks, casuarinas and banksias) can survive drier conditions, then few changes will occur. Watertables on the Tingalpa Creek section may be more critical than normal because this reserve occurs on highly drained sandy soils. The mangrove areas of the Wynnum Conservation Site section should be more or less immune to any changes unless the rising temperatures inhibit their growth, but their tidal zone habitat and the slow rate at which sea levels may alter should not pose a threat to their survival.

General Comments

Weeds are a major problem in the Brisbane park areas where abundant or increased fresh water supplies are available and this is usually along creek margins where the soil fertility is enriched. The mangrove swamps in the northern section of the Bayside Parklands are of interest with respect to the macrofungi, particularly in relation to some highly specialised polyporoid taxa. Surveys on macrofungi in mangrove ecosystems are few, threfore the possibly that species belonging to other groups of fungi are periodically present cannot be understated. It should be noted that at the moment, there is little (or no) data available on what macrofungal taxa occur in mangrove areas around Brisbane.

Fire is obviously the most dangerous immediate threat to the two eucalypt areas. Wallum survives easily after periodic "cool" burning, but intensely hot fires can do considerable damage if they destroy the underground root stocks that normally survive "cool" fire conditions. The authors consider that a schedule of controlled mosaic burning is still the best option in these reserves, while the mangrove area remains more or less "as is", with a weed suppression program in the bordering areas.of the grassland and the gully.

Plate 1. Chelsea Road: Eucalypt/casuarina woodland showing low but extensive litter levels and the bitumen walking and cycling path loop for this section of the reserves.

Plate 2. Chelsea Road: Low paperbark (*Melaeuca* sp.) thickets near the mangrove swamps.

Plate 3. Chelsea Road: Mangrove swamp and salt-marsh.

Plate 4. Chelsea Road: Denser woodland and forest inside the reserve showing thicker forest floor layer. There is abundant litter, bracken and specimens of coastal banksia.

Plate 5. Tingalpa Creek: Natural sandy surface track with thick eucalypt woodland and dense understory.

Plate 6. Tingalpa Creek: A view of a "wallum" area with emergent paperbarks.

Plate 7. Tingalpa Creek: A stand of eucalypts forming a small forest.

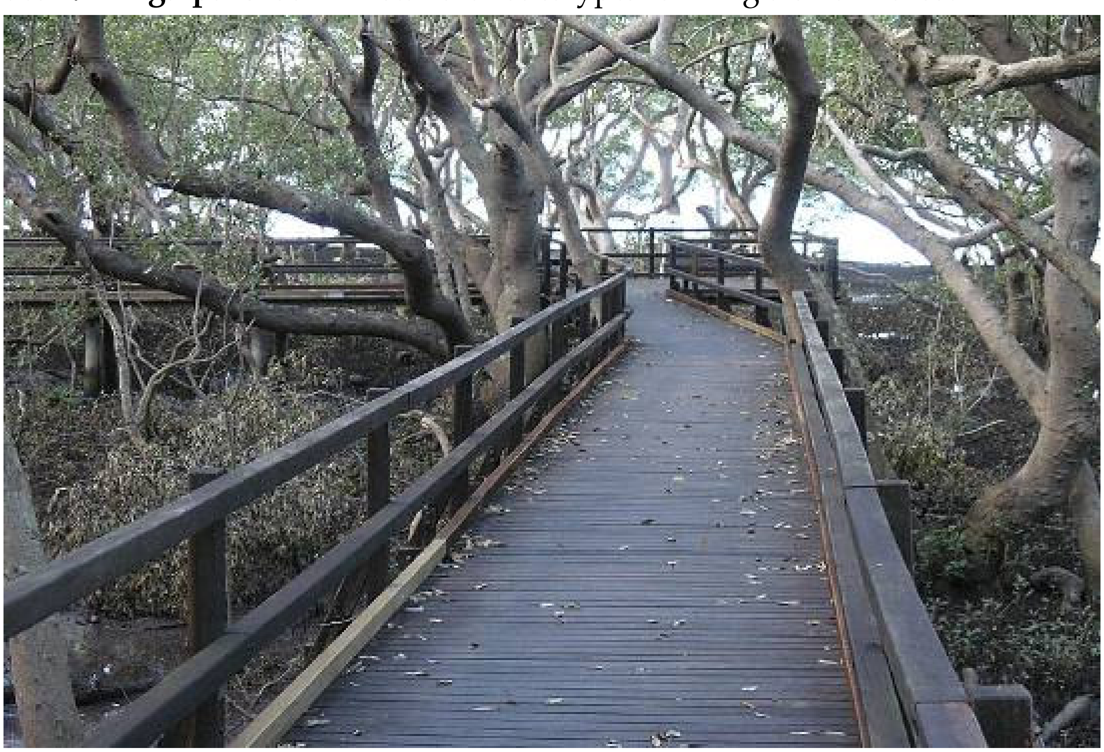

Plate 8. Wynnum North Reserve: A small section of the raised boardwalk path leading through the mangrove woodland.

Plate 9. Wynnum North Reserve: A regeneration section showing young growth of eucalypts and casuarinas bordering the mangrove swamps.

Boondall Wetlands

Size: 1000Ha. **Location**: 27° 20'S; 153° 04'E.

Vegetation

The park contains a mixture of open paperbark woodland [RE 12.3.6] (Plate 11), she-oak open forest [RE 12.1.1], marine couch grassland and samphire claypans [RE 12.1.2] and mangrove swamps [RE 12.1.3] dominated by *Avicennia* sp. (Plate 13). The woodlands contain Queensland blue gum (*Eucalyptus tereticornis*), swamp box (*Lophostemon suaveolens*), swamp she-oak (*Casuarina glauca*) and swamp paperbarks (*Melaleuca quinquinervia*) however for much of the park woodland, the dominant tree is the paperbark (Plate 10). Interspersed in this woodland are species of wattle (*Acacia*), fig (*Ficus*), and *Cupaniopsis anacardioides*. Some parts exhibit dense stands of *Casuarina glauca* (Plate 12), and these often grade directly and abruptly into the grassland regions. *Cupaniopsis anacardioides* forms dense thickets in some places and together with other species such as figs are almost certainly introduced via the droppings of bats or birds which roost amongst the mangroves. The extreme western end of the Reserve abuts onto the Gateway Arterial road and this area comprises eucalypt/paperbark woodland without track access.

Any of the taxa present can be considered salt tolerant to some extent as the salty soils and water-tables play large roles in determining the vegetation type. The vegetation seems extremely healthy however interspersed 'stag patches' (Plate 12) are apparently a normal component of the woodlands. These are clumps of dead dominants that are usually composed of extremely large dead trees. The precise reason for their deaths is not known, however it is thought to be related to age of the tree (hence the depth to which the roots penetrate), the height of the water-table (hence possible exposure to excessive salinity), weather conditions leading to drought, etc. It was observed that where the eucalypts attain a dominant stature, they are on ground that is slightly higher than the rest of the wetland.

Aspect and Features

The area is flat with tidal inlets and creeks penetrating into the grassland areas and the inlets are fringed by extensive mangrove thickets. Occasional areas of the land surface drop below its general levels by a metre at most and occasional small hillocks rise to one metre. The park is fringed by Cabbage Tree Creek and Moreton Bay on the northern side, Nudgee Road, Kedron Brook floodway and Brisbane Airport on the east, the Gateway arterial road more or less on the southern and western sides and the Shorncliffe railway line on the western boundary. Nundah Creek penetrates through much of the central part of the park. Most of the park is not accessible by trails or walking paths. Tidal influence and water table levels in this park will be of immense importance.

Walking Paths

There is a small walking track loop centered on the information centre at the park entrance, and another single track for both walking and cycling which runs for several kilometres from the information centre to Nudgee Road, just adjacent to the southern boundary of the park. The loop track has a very hard surface and in the swamp areas constitutes a raised board walk. The cyclists track has both raised boardwalks (where necessary) and a bitumen surface elsewhere. Cyclists (non-motorised) are permitted and the bitumen surfaces ensure little damage is done to the surrounding habitat. As in other locations surveyed, the bitumen paths encourage walkers/cyclists to stay on these prepared surfaces simply because the walking is so much easier. Vegetation benefits because soil compaction, weed seed dispersal and soil pathogen spread is minimized. The swamp areas further discourage "off-track" walking.

Fire

Apart from the western section near the Gateway Arterial, the evidence of fire suggests that it is sporadic and has little effect. There was almost no evidence of any recent fire on the single walking loop. The western section is subject to periodic burning which is almost certainly derived from the carelessness of "smoking driver" travelling on the adjoining motorway. Visual observation of these fires suggests that they are fairly intensive and destroy much if not all of the litter and logs on the ground.

Weeds

As with the Mt Coot-tha Forest, this park has a very large weed problem (Plate 14). Amongst the taxa identified as weeds were: Morning Glory (*Ipomoea*), *Ageratum*, *Solanum*, various ephemerals from the Asteraceae such as thistles, Red Natal grass (*Melinus*), *Physalis*, *Gomphocarpus* (cotton bush), Asparagus fern (two species), *Bryophyllum delagoense* (mother-of-millions), *Lantana*, *Panicum* and other exotic grass species. It is unlikely that complete weed eradication from this park is achievable. One of the key considerations therefore, is in what ways climate change will alter how the weeds react to the hotter and/or drier climates.

Sensitivity to Climate Change

It is very possible that this park may be quite sensitive as a whole to climate change. Some aspects to consider are the possibility of rising sea-levels, the balance of fresh water and saline water tables and indefinite submersion of the riparian and marine plain portions of the park. In addition, even if sea levels do not rise, very long dry periods may alter the water balance within the park soils. Some of these normally water-saturated or mangrove-inhabited soils break down under these dry conditions to release heavy metals and acid compounds which can be highly damaging to the plants and may even render parts of the park virtually sterile. For the moment, thought should be given to reducing the fire impacts in the western end, even if only to strip burn along the arterial road edges.

General Comments

The bikeway path penetrates some unusual and extensive pure stands of *Casuarina glauca*. These are of immense interest for two reasons: any mycorrhizal taxa that are found are specific on those trees and second, the taxa will be somewhat salt tolerant, an aspect that is currently little investigated for the Australian macrofungi in general.

Plate 10. Paper bark woodland showing large infestation by exotic grasses. This area would be subject to periodic flooding due to the low-level and flat terrain.

Plate 11. Boardwalk in the paperbark/eucalypt woodland; the paperbarks are dominant.

Plate 12. The left image shows the casuarina/eucalypt woodland mixture often encountered on the paths, while the right image shows the so-called "shag thickets" of tall, dead casuarinas which are interspersed amongst the normal, healthy woodland.

Plate 13. Grassland with claypans intermixed and terminating in the mangrove thickets along the salt-water marshes and inlets.

Plate 14. A small sample of the wetland's weed problem. This is an outbreak of *Gomphocarpus*, or cotton bush, which seeds prolifically and uses the wind to transmit the seeds over long distances.

Brisbane Botanic Gardens - City

Size: 20 Ha. **Location**: near city centre 27° 28'S; 153° 01'E.

Vegetation

A mixture of: eucalypt woodland/forest and exotic woodland and forest species, extensive maintained grassland areas with integrated exotic specimen trees (Plate 15), a closed canopy rainforest gully(Plate 16), and some river marginal mangrove thickets (Plate 17). The grassland areas are carefully mown and maintained and the exotic garden or specimen vegetation includes representatives from all over the world including *Ficus, Pereskia, Hibiscus,* etc. The native gardens or stands of trees include various species of *Eucalyptus, Archontophoenix, Allocasuarina, Banksia, Acacia*, etc. The rainforest gully also has extensive areas of undergrowth, mostly exotics. Most of the gardens are heavily mulched.

The park policy appears to be that fallen branches and logs should be left where they are on the various gardens or areas in the rainforest (unless they restrict public access, present a danger or are aesthetically challenging) and this produces a very natural appearance in those areas. Fallen branches are removed from around isolated specimen trees within the grassland areas which experience high public usage.

Aspect and Features

The southern part of the park has several gentle rising slopes towards the park boundary and a gully but there are no features that could be strictly termed "hill", and the general area is more or less flat except for an abrupt rise at the river banks.

Walking Paths

There is a very extensive system of tracks for access by pedestrians and small vehicles, much of which has a bitumen surface and is a remnant of the earlier period when motorized vehicles had access to the park. Only park maintenance vehicles now have access, however bicycle riding (non-motorised) is permitted in the park. There is little evidence of any "unauthorized" paths created by movement of people from off the designated paths. Pedestrian use of the park is very heavy both on the paths or grassland areas, however no discernable damage is occurring.

Fire

There is no evidence of fire, and the likelihood of fire in the future is considered remote. The extensive areas of grassland isolate any of the possible fire prone areas and there is no possibility of fire causing extensive damage to the park at any time.

Weeds

The park is remarkably free of weed species. There are occasional small amounts of herbaceous weeds, but these are sporadic and hand weeding is all that is required.

Sensitivity to Climate Change

Most comments made on the Mt Coot-tha park are applicable to this park. Given its proximity to the river, water supply is of little concern because the park benefits from a very close water table. The effects of climate change on the higher plants are therefore likely to be confined to those species that simply cannot tolerate higher temperatures. The rainforest gully is likely to experience minimal stress since the proximity of the water table should provide ample water. The eucalypt and native section should survive for a similar reason. There should be no impact from either fire or weeds.

General Comments

The general recommendation here is to maintain the park "as is". The present "log policy" means that there is excellent wood diversity and the possibility of significant polyporoid genera diversity. The mulch, extensive grasslands, high humidity and assured water supply make this a very good reserve for litter and grassland macrofungal taxa. This is the only mangrove reserve in the centre of the city area and as such it is important to conserve this site because the macrofungal species that can deal with mangrove conditions are limited to the rotting wood that is available and are likely to be somewhat specialised.

Plate 15. Grassland areas in the City Botanic Gardens showing the large expanses of lawn, heavily mulched gardens and numerous exotic specimen trees. The stand of native species of *Eucalyptus* is are not shown here however it forms a noticeable display in the southern section of the park.

Plate 16. Artificial rainforest gully with closed canopy, mulched gardens and exotic species undergrowth.

Plate 17. Fringing mangrove swamp on the Brisbane River margins.

Brisbane Botanic Gardens (Mt Coot-tha)

Size: 52 Ha. **Location**: 27° 28′S; 152° 58′E.

Vegetation
A mixture of: grassland, an artificial woodland and garden based largely on exotic species (Plate 18); an area of native woodland and forest species (Plate 19); and amenities for public use. An artificial paperbark swamp (*Melaleuca* sp.) and waterlilly lagoon are also present (Plate 20). The grassland areas are carefully mown and maintained and the exotic vegetation includes representative taxa from many overseas countries. The native stands include various species of *Eucalyptus, Archontophoenix, Allocasuarina, Banksia, Acacia, Callitris, Araucaria* etc. The gardens are heavily mulched. In the natural forest and woodland areas, the park policy (as communicated by park gardeners) is that fallen branches and logs should be left where they are to allow a very natural appearance to be produced in those areas – unless the position of the log presents a public hazard or is detrimental to the aesthetic qualities of the particular area.

Aspect and Features
The park lies on part of the eastern portion of Mt Coot-tha. Geographically, there are variations from flat ground at the very base of the park to steeply rising slopes and gullies in the upper section. A natural gully has been changed into a large lily lagoon and paperbark swamp. The gardens are bounded on the top and ± western side by the Mt Coot-tha Forest Park and on the southern and eastern sides by the expressway and road systems. On the northwest side, there is a large quarry which forms an artificial barrier between the Gardens and the Forest Park.

Walking Paths
There is an extensive network of road and walkway systems, much of which has a bitumen surface. There is little evidence of any "unauthorized" paths created by movement of people off the designated paths. Vehicle and pedestrian use of the park, especially the grasslands, is very heavy, however no discernable damage is occurring.

Fire

There is no evidence of fire, and for the area containing grassland and exotic taxa the likelihood of fire in the future is considered remote. The native eucalypt areas may suffer some fire damage if the adjacent Mt Coot-tha Forest Park itself experiences fire, however these are most likely to be of low intensity and therefor will do little damage.

Weeds

That part of the park containing grassland and gardens with exotic taxa is remarkably free of weed species. This is done by hand weeding and spraying. At the park margins and in the native eucalypt area, there are some small infestations of *Ageratum* and similar annuals, but no *Lantana* was sighted. The areas of the Park which are most vulnerable to weed incursions are the margins near the roads, and the quarry, which itself is heavily weed infested. It is also possible that weeds might encroach from the Mt Coot-tha Forest Park, or be a result of infection from vehicular and pedestrian traffic. Under the present practices of intensive maintenance, there is little likelihood of any major weed infestations

Sensitivity to Climate Change

Other than taxa that might be affected by temperature rises, it is unlikely that much of this park will be extremely sensitive to climatic change given that water supplies are not a major problem. The large ponds and the paperbark swamp may be more difficult to retain (but certainly not impossible) if the climate change produces an excessively dry climate, however the eucalypt and native section should survive intact quite easily for a similar reason. Given the present park policies, there should be no impact from either fire or weeds.

General Comments

The general concept here is to maintain “as is”. As with the Brisbane City Botanic Gardens, the present “log policy” means that there is an appreciable availability and variety of decaying wood, and thus a potentially excellent substrate source for supporting significant polyporoid genera and species diversity. The mulch and extensive grasslands make this a very good habitat for litter and grassland macrofungal taxa given the assured water supply. The eucalypt and native areas are also useful as a conserved weed-free zone, representative of the original woodlands of the Mt Coot-tha region.

Plate 18. A portion of the Botanic Gardens showing the extensive grasslands, exotics in mulched gardens and bitumen road access.

Plate 19. A heavily mulched garden with native species (*Banksia*) and part of the native forest (*Eucalyptus*) in the background.

Plate 20. The artificial lagoon with waterlillies paperbark swamp and surrounded by a natural stand of natural *Eucalyptus* spp.

Brisbane Koala Bushlands

Size: 827Ha. **Location**: 27° 34'S; 153° 09'E (Alperton Road Visitor Node; 84Ha)
. 27° 33'S; 153° 10'E (J.C.Trotter Memorial Park; 83Ha)

Vegetation

Alperton Road Visitor Node and J.C.Trotter Memorial Park are two of the major components of this network of reserves, which extends from Mt. Petrie at Belmont to Tingalpa Creek at Burbank. Both of these reserves were investigated and and provide a reasonable sample of what is to be expected in the other reserves and parks which comprise the Bushlands. Both of them have designated pedestrian walking paths while the Stockyard Creek section of the park is more or less bisected by a horse riding trail. Both visited parks consist of woodland and forest and much of the native vegetation is intact. The Alperton Road Visitor Node is a eucalypt/casuarina woodland (Plate 21) with an open understorey containing native grasses. There is excellent litter deposit and there are abundant logs and small branches. The site appears to be managed so that it remains as natural a state as possible. The forest/woodland floor is remarkably open with mostly litter, scattered grass tussocks and occasional shrubs. Some areas have a dense, closed canopy casuarina woodland (Plate 22) in which only the casuarinas are present. There is a gully section (Plate 23) which approaches a closed gallery woodland although it is based on eucalypts. Taxa present include: vine species, *Glochidion sumatranum*, *Acacia fimbriata* and *Daviesia* sp. There are abundant specimens of *Lomandra*. There is also a small section of paperbark swamp (currently mostly dry) (Plate 24) and associated shrub story of *Leptospermum*.

The J.C.Trotter Memorial Park is also woodland/forest (Plate 25), however the structures present are quite different. The woodland rapidly grades into a true eucalypt forest with abundant examples of "scribbly gum". Other genera forming small trees include *Banksia* and *Alphitonia*. The understorey is dense (Plate 26) and consists of grasses, at least some small shrubs of various kinds (including *Banksia robur*) and abundant sedges. This part of the reserve is almost a form of "wallum". Finally there is a dense paperbark swamp with flooded areas – the water coming from the Tingalpa Reservoir (Plate 27).

Aspect and Features

Both reserves range from gentle slopes to level ground, apart from the gully in the Alperton Road Visitor Node where the sides of the gully are often quite steep. The soils are shallow, appear to be quite poor, are very well drained and form firm surfaces. The J.C.Trotter Memorial Park is essentially flat but does very gently slope to the water catchment area that keeps the paperbark swamp flooded. It has sandy track surfaces.

Walking Paths

Both parks examined have facilities for pedestrians. They differ in that the track system accessed at the Alperton Road Visitor Node has been given a durable bitumen surface and consequently there is little incentive for pedestrians to leave the circular loop track even though the open forest/woodland floor offers little impediment to such off-track incursions. The tracks in the J.C.Trotter Memorial Park have a natural surface of soft sandy soil and are intended for horse use as well as pedestrian traffic. Dung deposits were noted. The very dense understory of shrubs and sedges inhibit off-track incursions in this part of the reserve system also.

Fire

The two reserves examined have undoubtedly been fired in the past, however there does not seem to have been any such fire in the past five years because the litter deposits are dense (which may equally be the result of prolonged drought stress) and there is minimal visual fire charring evident.

Weeds

These two reserves are remarkably free of weeds. At the Alperton Road Visitor Node the woodland/forest floor was virtually bare of weed species apart from a few ephemerals. Weeds present were concentrated on the moister creek margins and included *Lantana camara* and *Ageratum houstonianum*. No marked weed invasion was noted for the other reserve.

Sensitivity to Climate Change

Given the nature of the natural vegetation, with most, if not all of the current taxa well adapted to long dry periods, it is difficult to see how climate change will impact markedly on this park other than to increase the number of fires. Mosaic burning at regular intervals should, however, decrease this problem. The flooded paperbark woodland in the J.C.Trotter Memorial Park may be at risk under long periods of drought if the waterlevels in the associated Tingalpa Reservoir fall appreciably.

General Comments

As is the case with similar dry eucalypt woodlands/forests, the general concept here is to maintain "as is". Mosaic burning to reduce fire intensity and the possbility of local arson is probably the best strategy. Our interpretation of current conditions is that if climate change raises temperature and produces longer dry periods, then the current assemblage of weeds will find it increasingly difficult to survive and spread. This, however, would not preclude a "new assemblage" of different weed species moving in to take their place.

A fresh collection of the ectomycorrhizal genus *Pisolithus* was found at the base of a eucalypt.

Plate 21. Alperton Road Visitor Node: eucalypt woodland showing the open structure, the bitumen-surfaced path and the weed free understory.

Plate 22. Alperton Road Visitor Node: dense, closed casuarina woodland with litter and relatively clear understory.

Plate 23. Alperton Road Visitor Node: gully with denser vegetation based on eucalypts. Weed infestation occurs along this section of the reserve.

Plate 24. Alperton Road Visitor Node: stream-fed paperbark swamp (currently dry); dense understory of ferns and native grasses, sedges and water-dependent native herbs.

Plate 25. J.C.Trotter Memorial Park: eucalypt woodland/forest with mixed banksia and casuarina; the ground layer supports a much denser growth of native grasses etc.

Plate 26. J.C.Trotter Memorial Park: woodland; dense ground cover of sedges and *Leptospermum*; natural sandy surfaces occur on most tracks except near the entrance.

Plate 27. J.C.Trotter Memorial Park: paperbark swamp (*Melaleuca* sp.) maintaned by the upper reaches of the Tingalpa Reservoir.

Chermside Hills Reserves

Size: 121Ha. **Location:** 27° 23′S; 153° 00′ 12″E. (Raven Street, 33Ha)
27° 22′S; 152° 59′ 12″E. (Chermside Hills, 73Ha)

Vegetation

The Reserves consist of two large units (Raven Street Reserve [33Ha] in the south and Chermside Hills Reserve [73Ha] in the north) which are linked by a third smaller area (Milne Hill Reserve [15Ha]). The Milne Hill Reserve contains heathland, however since the Chermside Hills Reserve also contains similar heath, the omission of the Milne Hill Reserve was not considered detrimental to the survey.

The **Raven Street Reserve** contains large and very healthy woodlands of *Eucalyptus* spp. but there is also a very large variety of native species as well, including: *Melaleuca, Alphitonia, Casuarina, Banksia, Acacia, Lomandra* and *Daviesia* (Plates 28, 30). There is also a well developed gully (Plate 29) with a nearly closed canopy and forming a gallery forest, containing dense fern thickets on the forest floor as well as specimens of tree fern (*Cyathea* spp.) and palm (*Archontophoenix*) in its upper sections. The eucalypt woodland/forest floor appears to be representative of the original indigenous flora, comprising native grass species in tussocks (including *Imperata cylindrica*)and scattered clumps of bracken (*Pteridium esculentum*). The litter is usually deep and well developed. Of great interest are the very dense *Xanthorrhoea* thickets (Plate 32) on the northern slopes of the Reserve since this vegetation type seems only to be found here and in the associated Chermside Hills Reserve.

The **Chermside Hills Reserve** contains a much similar forest (Plate 34) with more or less the same dominants (eg. *Eucalyptus* and *Casuarina* spp.) but based on a poorer and more gravelly soil than the finer loams of the Raven Street Reserve. There are also specimens of *Callitris* sp. and it is known that at least seven uncommon plant taxa are to be found in this Reserve. Additionally, the Chermside Hills Reserve contains an extensive stand of heathland with scattered and emergent *Eucalyptus* spp. that give the appearance that the area is predominantly woodland rather than a heath (Plate 35). The forest near the Reserve entrance grades into woodland on the poorer and higher soils, but again contains very few weed taxa and contains excellent examples of indigenous flora. There is usually deep litter associated with these heathlands. The heath area has a well developed shrub and herb layer and at least some of the taxa present include: epacrids, *Pultenaea*, *Leptospermum*, *Banksia*, *Persoonia*, *Petrophile*, sedges, *Xanthorrhoea*, *Jacksonia* and *Lomatia*. The heath understory can be extremely dense and observations indicate that it is in excellent condition. A gully on the upper slopes contained some extensive fern growth and abundant specimens of *Acacia fimbriata*.

Aspect and Features

The **Raven Street Reserve** contains a gully with occasional steep sides, but the remainder is gently sloping to a small northern hill. This is not particularly prominent, nor has it any deep gullies or steep slopes associated with it. The **Chermside Hills Reserve** contains several steep gullies and some much higher rising hills with steep slopes. There is plenty of evidence of periodical fire activity, however there does not seem to be any indications of major damage done to any part of this forest. This would seem perfectly normal given that heath is naturally fire resistant and indeed periodic burning is a natural part of healthy heath regeneration cycles. The enormous *Xanthorrhoea* "woodland" on the northern slopes of the Reserve is unique amongst the Brisbane park lands and should be protected if at all possible. Fires on these northern slopes are likely to be more severe if they are not carefully managed, however the vegetation present during the survey indicates that so far the Reserve has survived more or less intact and has regenerated extremely well. Considerable work has been done on anti-erosion measures along the creek banks using wire-bound rock walls.

Walking Paths

All three Reserves contain walking trails. The **Raven Street Reserve** has bitumen surfaced paths and the use of bicycles is permitted. Active discouragement of off-track access has been made through the use of barriers where short-cuts may be tempting. Tracks through the **Chermside Hills Reserve** have a natural surface and there is some occasional erosion degradation of the tracks on steep slopes, although this is never severe. The off-track paths are fenced off and sign-posted so that all attempts are being made to minimise disturbance of the heathland from "unauthorised trail making".

Fire

There is evidence of fire but the evidence seems to indicate that the last fire was at least 3-5 years ago and that the bushlands have recoved well. Fire seems to be rare in the area near the **Raven Street Reserve** information centre and this absence is essential for the survival of the fern gully and its closed canopy regeneration. On the upper slopes of this part of the Reserve system, there is a little more evidence of fire, but again, regeneration has been effective and complete. This woodland and forest is naturally fire resistant to "cool burns", however hot wild fires could damage the area considerably. Our observations strongly suggest that similar conditions apply to the **Chermside Hills Reserve** with the proviso that periodic burning of the heathland is an essential part of its management, provided this is done periodically to give "cool burns". Careful management of any fires is required to ensure that these are kept at low ground level and allow much of the heath flora either to escape death by the usual fire resistant measures or to produce fire-induced seeding. Currently, the litter depths (<3 ◎ 10cm) in both parts of the Reserves that were surveyed suggest that the flora is extremely healthy and has recovered fully from the last periodic fire.

Weeds

Much of the **Raven Street Reserve** is remarkably free of weed species, however the gully/gallery forest becomes heavily infested with various weeds in its lower and more open sections (Plate 31). These include *Ageratum*, *Panicum*, "mother of millions", *Ochna*, *Gomphocarpus*, *Solanum*, *Celtis*, *Asparagus* sp., *Ipomoea*, and a wide variety of exotic grasses. Specimens of *Ficus* (probably *F. watkinsiana*) and *Brachychiton acerifolius* (flame kurrajong) were also noted, but these could either be native or introduced via bird or bat droppings – in which case it could be argued that they are "indigenous" to the area. There are also an introduced legumes: a scrambling vine (either *Macroptilium* or *Neonotonia*) and *Senna* is also present. Apart from a small infestation of "mother of millions" near the Federation Street access point, the remainder of the park is remarkably weed free. It is very obvious here that the weeds are more or less restricted to the moister and richer soil conditions of the creek banks and find it "difficult" to invade the drier conditions of the main part of the park. The **Chermside Hills Reserve** is also remarkably weed free, but as with the southern section, there is heavy weed infestation along the banks of Cabbage Tree Creek (Plate 33). Genera noted included: *Asparagus*, *Citrus*, "ginger", *Cupaniopsis*, *Lantana*, *Cyperus*, *Ricinus*, *Urena*, Cordyline, *Morus*, *Homalanthus* and *Stephania*. This weed infestation is far more severe than that at the Raven Street Reserve which has considerable hand weeding applied to its areas near the upper parts of the fern gully.

Sensitivity to Climate Change

The **Raven Street Reserve** is likely to be more or less resistant to climate change, apart from the fern gully near the information centre. This is because the majority of the taxa are already drought tolerant and the poor dry soils inhibit large scale weed invasion. The fern gully is most vulnerable simply because its existence depends solely on water, without which it would revert to an open canopy eucalypt forest or woodland. For the same reasons, the **Chermside Hills Reserve** will react in the same way. This part of the Reserve group does contain a creek flora, but it is not as closed as the Raven Street gully and weed invasions are prolific. Our observations here are also strongly suggestive of the fact that in these dry eucalypt areas, weed invasion is not likely to be a major problem under the much drier conditions. Weeds will only be invasive near more abundant water supplies near the creek systems. We expect that this area will readily survive drier conditions as long as it is not over stressed by fire and the mycorrhizal flora should readily survive under these conditions as well.

General Comments

The general concept here is to maintain "as is". Mosaic burning to reduce fire intensity and the potential for local arson is probably the best strategy, together with weed control, if possible, along the creek or gully margins. The poor soils and vegetation indicate a thriving ectomycorrhizal flora and heavy rains should produce prolific evidence of this. Some aged polyporoid fruiting bodies were noted, but apart from *Pycnoporus coccineus* no positive identifications were made or attempted. Some fruiting bodies of *Cymatoderma elegans* var. *lamellatum* were noted from the fern gully at Raven Street Reserve. This area's extensive heath lands make it extremely valuable as a unique sample of the original fungal flora of the Brisbane region.

Plate 28. ***Raven Street Reserve***: mixed eucalypt/casuarina forest with bitumen surfaced path and barriers to prevent off-track incursions; a habitat rich in ectomycorrhizae.

Plate 29. ***Raven Street Reserve***: Fern gully showing closed canopy and dense forest floor fern layers.

Plate 30. ***Raven Street Reserve***: mixed, open casuarina/eucalypt woodland found over much of the reserve.

Plate 31. ***Raven Street Reserve***: dense weed problems along the lower portions of Downfall Creek.

Plate 32. ***Raven Street Reserve***: thickets of grass-trees, *Xanthorrhoea* sp. This floristic structure seems to be unique to this particular Reserve

Plate 33. ***Chermside Hills Reserve***: weeds along the creek bank showing an infestation of a large species of *Cyperus*.

Plate 34. ***Chermside Hills Reserve***: mixed eucalypt/casuarina forest with native understory. Weeds do not seem to be able to encroach upon these areas.

Plate 35. ***Chermside Hills Reserve***: Grass-trees and heath with emergent eucalypts.

Karawatha Forest

Size: 900Ha. **Location:** 27° 51′S; 152° 05′E.

Vegetation

A mixture of: eucalypt woodland/forest and of native species (Plate 36); some denser eucalypt stands in gullies; the northern area has vegetation approaching heath (*Boronia* sp. etc.) but not true areas of heath (Plate 40); the southern section also holds paperbark swamps (Plate 41), reed beds (Plate 43), a lagoon system, areas of *Leptospermum* swamp and a small amount of sub-heath with *Banksia* sp. (Plate 7). There are some almost pure stands of *Allocasuarina* (Plate 37). There are some amenities at the entrance points and an excellent walking track system. A visual general sampling suggests: *Eucalyptus, Acacia, Allocasuarina, Alphitonia, Leptospermum, Lomandra, Themeda, Cymbopogon, Aristida, Boronia, Smilax, Xanthorrhoea, Banksia,* etc. but the park's flora is already known. The gullies can be as much as 80% closed canopy so the vegetation on the floors is lush. In the open woodlands, the floor covering varies from patches of exposed soil, shallow to deep litter, or dense grass. Some fern (bracken) covering is evident in the gullies (Plate 38).

Aspect and Features

The northern part of the forest has several gentle slopes and gullies rising to a sandstone capped central hill, on the western side of which are much steeper gullies. These show evidence of periodical firing and the damage here is more severe because of updraft conditions created by the land gradients.

Walking Paths

There is a very extensive track system. The park is based on hard sandy loam and quartzite soils and is also used for trail bike riding (non-motorised). The path surfaces are extremely hard and erosion/damage resistant. There is some evidence of unauthorized paths, but these are more in the realm of shortcuts and there is no evidence that users deviate from those shortcuts......they are mostly on gentle gradients and there was no evidence that these short cuts were causing any erosion.

Fire

The evidence of fire is seen all over the park and generally appear to be of the mosaic type rather than a fierce overall and destructive burn. The only exception to this is in the gullies in the NW area where some high intensity blazes have moved through the area and the litter and small branches have been destroyed (Plate 39). The rest shows relatively low intensity burns which are normal for eucalypts and such fire intensities are readily tolerated by them. The litter shows how some areas have escaped fire for considerable periods ......depths of <3 to 10cm were recorded.

Weeds

Much of the park is remarkably free of weed species. There were one or two plants of *Lantana* in the southern section, but it did not seem to be able to spread. Around the sites used by people, there were more weed species such as *Ageratum* and there is an invasion of *Senna* sp. in the eastern area near where housing begins. This area also shows large scale invasion of a species of tropical grass. Of some concern is a patch of "mother of millions" in the southern end of the wallum area..

Sensitivity to Climate Change

The *northern section* is probably best able to survive the predicted drought component of climate change. This is because the eucalypt woodland is naturally a drier ecosystem and from present observations, the woodland and forest in that part of the park show little damage (if any) from the past drought. The open and drier conditions also mean that this part of the park will be far more difficult for weeds to establish, other than annuals that take advantage of transient favourable conditions after rain. We expect that this area will readily survive drier conditions as long as it is not over-stressed by fire and the ectomycorrhizal flora should naturally survive under these conditions as well.

The *southern section* is less likely to be viable if prolonged drought occurs. This is because it depends on its existence for water drainage from the northern end of the Reserve, and if this is reduced, then so too will be the resultant water reservoirs. This could impact on the *Melaleuca* and *Leptospermum* swamps together with their unique associated macrofungal flora.

General Comments

The general concept here is to maintain "as is". Mosaic burning to reduce fire intensity and the potential of local arson is probably the best strategy. The park has a mammal population and a wallaby was sighted during the afternoon.......The poor soils and vegetation indicate a thriving ectomycorrhizal diversity and heavy rains should produce prolific evidence of this. Even under the dry conditions during this survey we were able to confirm material of: ***Amanita***, *Calvatia*, ***Inocybe***, *Phellinus*, *Melanoleuca*, **Pisolithus**, *Pulveroboletus*, *Pycnoporus and* ***Russula***. Mycorrhizal genera are bold faced.

Plate 36. The mixed eucalypt/casuarina woodland that dominates much of the park. This habitat is especially rich in mycorrhizal species of macrofungi.

Plate 37. A pure stand of *Allocasuarina* ("casuarina"). Stands such as this are of immense interest as they provide strong evidence of tree/fungal associations.

Plate 38. A fern gully; this vegetation type is quite dense and occasionally forms an almost closed canopy ecosystem.

Plate 39. The northern slopes showing the effects of intense fire. All ground litter and logs have been destroyed and burn marks extend up the trees. Recovery is slow.

Plate 40. The heath-like understory found in the southern part of the park consisting largely of a species of *Leptospermum*. This seems to recover well after fire.

Plate 41. A paperbark swamp area, with *Melaleuca quinquinervia* as the dominant. This area is likely to be heavily impacted if the results of climate change manifest as a continuously drier climate since the run-off from the northern section may not be able to sustain this amount of surface and subsurface water.

Plate 42. A section of the *Banksia* heath-like area near the paper bark swamps in the southern section. Usually species of *Banksia* withstand fire by seed dispersal triggered by the heat of the fire when the seeds are ejected into the cold ashes.

Plate 43. Extensive swamp and reed beds in the southern section of the park. This is an area that will probably be heavily impacted if the results of climate change manifest as a continuously drier climate since the run-off from the northern section may not be able to sustain this amount of surface and subsurface water.

Mt Coot-tha Forest

Size: 1500+ Ha. **Location**: 27° 29′S; 152° 57′E.

Vegetation

The park is a woodland/forest mixture (Plate 44) probably based on the original flora of the Mt Coot-tha area. There are also small areas of grassland that have been artificially inserted and maintained as public recreational areas. The trees form a fairly dry and open eucalypt forest with an understory that is predominantly grasses with sporadic forbs. Taxa such as *Davesia villifera*, *Dianella caerulea*, *Dodonea triquetra*, *Doodia caudata*, <u>*Duranta erecta*</u>, *Eustrephus latifolius*, *Hibbertia stricta*, *Hovea acutifolia*, <u>*Ochna serrulata*</u>, *Olearia nernstii*, <u>*Phytolacca octandra*</u>, *Pimelia linifolia* ssp. *linifolia*, *Smilax australis*, <u>*Solanum torvum*</u>, *Swansonia brachycarpa* and <u>*Tithonia diversifolia*</u> (introduced taxa are underlined). Other native taxa include species of *Acacia fimbriata* and *Allocasuarina torulosa* and components of this "understory" can reach heights of as much as 15 metres. The deep gullies are mostly still eucalypts, however the gully at Simpson's Falls does have some relict rainforest taxa present; it is not a closed, gallery, rainforest gully but is rather a wet sclerophyll gallery forest. The J.C.Slaughter Falls area has what are described as "vine thickets" (Plate 47) and some very localized gallery, wet eucalypt, often nearly completely closed canopy forest/woodland with scattered palms (e.g. *Archontophoenix* and at least one other genus), *Podocarpus elatus*, *Ficus macrophylla*, *Grevillea robusta*, *Araucaria cunninghamii*, and several other taxa normally associated with rainforests/notophyll vine forests. The sheltered, moister and nutrient-enriched deep gullies are able to support denser vegetation than the mountain summit and often in these secluded niches there is a thick understory of ferns and dense thickets of lianas. These lianas are usually confined to the locality of a single tree where they hang in festoons from the branches. Some of the rainforest taxa are native to the area but it is likely that others are either garden escapes or deliberate introductions by park authorities in the past.

The native forest and woodland areas are given very little maintenance so that the various habitats are left as natural as possible

Aspect and Features

The park lies on part of the east and southeast southern portions of Mt Coot-tha across the top and is contiguous with Brisbane Forest Park on its western boundary. Most of the park is hilly to mountainous with steep slopes and deep gullies. The gullies are seasonal as regards water flow and for much of the year they are dry. Whilst the park may receive additional moisture from its coastal proximity, the frequently poor, highly drained, often shallow soils ensure that, for the most part, a dry, open sclerophyll forest results. The gullies which support vine thickets or relict rainforest taxa do so through percolation of additional water and leached nutrients from higher up the mountain. There are no natural barriers comprising the park boundaries and invasion by exotics is therefore almost impossible to prevent.

Walking Paths

There is extensive access for vehicles and pedestrians. A two-way bitumen road completely encircles the summit of the park, more or less splitting the forest into large eastern and western ends. Both are extensively serviced by walking trails, however it would probably be fair to say that much of the park traffic is concentrated on the eastern section because this is the part with ready access to the restaurant amenities, the lookout, the television stations and the walking trails which allow easy access to park features. Little evidence of any "unauthorized" off-track movement from the designated paths was noted. Vehicle and pedestrian use of the park is extremely heavy but vehicles are restricted to the road and pedestrians/tourists tend to concentrate on the summit lookout area rather than move in large numbers through the park trails. Visible damage to track proximity was not seen during the visit.

Horses are permitted throughout this forest. These animals are known to introduce weed taxa into areas because their digestive system does not destroy seed viability completely and their dung deposits frequently contain large numbers of seeds from weed species. Herbicides are used on track margins and it was evident during our inspection that weed sprays had been applied to a band of the high grass along the walking trails and along the road. Such treatment would facilitate easy ignition of the dead, dried out foliage and, as part of the councils management policy, obviously functions as a precursor to planned low-moderate intensity burns of portions of the forest during the cooler months of the year..

Fire

There is considerable evidence of fire, and the whole area is fired periodically through deliberate litter reduction policy (in process during the project data collection), accident (e.g. cigarette butt/ash disposal from cars) or from arson. The park is likely to be heavily impacted by fire because the steep gullies will enhance the updraft effects on the fire and contribute to extremely hot burns. There is also enormous invasion by a variety of tall, robust exotic grasses. These produce an immense amount of flammable material towards the end of summer and given the often careless attitude of visitors to fire hazards and the propensity for arsonists to deliberately light fires, the dead grass almost ensures that some parts of the park will be burnt annually. Observations suggest that the dominants of the woodland and forest are largely unaffected, however intense fires can damage or destroy the new saplings (that will replace the present dominants) before they are large enough to resist fire as effectively as the mature trees.

It was noticeable that where the litter-reduction fire encroached upon the vine thicket flora, the impact was quite severe with both palms and vines being very badly damaged or destroyed. There is reason to believe that the park under-story is currently in a successional stage, esepecially when compared with the presumably mature pre-settlement vegetational community, and some shrub species may already be much rarer than they were 200 years ago. While this is supposition, it is nevertheless a matter to be considered in a review of the effects of fire on the park.

Weeds

This park has a severe weed problem. A list of exotic taxa sighted during the inspection (which can be considered very incomplete), includes: *Ageratina riparia*, *Ageratum houstonianum*, *Asparagus aethiopicus*, *Bidens pilosa*, *Canna indica*, *Duranta erecta*, *Erythrina* sp., *Euphobia heterophylla*, *Koelreuteria elegans* subsp. *formosana*, *Lantana camara*, *Leucaena* l*eucocphala* subsp. *leucocephala*, *Ochna serrulata*, *Opuntia* sp., *Passiflora foetida*, *Passiflora subpeltata*, *Schefflera actinophylla*, *Schinus terebinthifolius*, *Solanum torvum*, *Sonchus oleraceus*, *Tagetes minuta*, *Tithonia diversifolia* and exotic grasses including: *Chloris gayana*, *Chloris virgata*, *Digitaria didactyla*, *Eleusine indica*, *Eragrostis tenuifolia*, *Melinis repens*, *Paspalum dilatatum*, *Paspalum urvillei*, *Sorghum arundinaceum*, *Sporobolus africanus* and *Urochloa decumbens* (immense infestations to the extent that the native grasses of the eucalypt woodland have now been displaced in many locations) (Plate 45). The gully at Simpson's Falls (Plate 46) has *Ipomoea indica*, *Lantana camara*, *Thunbergia alata* and other exotics which more or less dominate the gully completely apart from the trees. At one point, an entire slope was observed to be covered in lantana. The gardens established around the television stations also contribute to this problem as they contain exotics which can escape into the park quite readily.

It is difficult to see how weed control will ever be established in the park given the current public access requirements of both pedestrian and vehicular traffic, horses, the fact that the park is already heavily inoculated with considerable amounts of weed taxa, many of the exotic grass species have persisent soil seed banks whilst the native grasses tend to have itinerant seed banks, and finally the fact that the cost of eradicating the weeds would probably be ongoing and prohibitive unless a very large volunteer system could be put in place. The proximity of homes to the park boundaries on the western side also ensures that incursions by exotics and weeds will continue from that area.

Sensitivity to Climate Change

Other than taxa that might be affected by temperature rises, it is unlikely that the native dominants of this park will be extremely sensitive to climatic change. The eucalypts are already able to withstand considerable periods of drought and given that the park is mostly a dry sclerophyll forest, there is little likelihood of damage by climate change alone. We predict that the most significant damage will occur from the combination of raised temperatures and increased fire intensity, coupled with the topographical problem of the steep mountain slopes and the consequent enhanced updrafts. Weeds are already a massive problem and it is difficult to see how their impact could worsen. Based upon our observations of both Karawatha and Toohey forest parks, where the dry, poor soils seem to have largely inhibited aggressive weed taxa such as lantana, it is possible that weed problems may diminish to some extent if a drier climate results. The vine forests and rainforest relicts in the gullies should remain intact if fire does not impact upon them however this particular habitat seems to be the most sensitive to fire damage.

General Comments

The park does still contain a large reservoir of dry eucalypt forest that will act as an excellent reservoir of mycorrhizal taxa. Litter taxa are damaged extensively by fire and may take several years to re-establish. Implementing a plan of deliberate mosaic burning to diminish the number of, and potential for severe Park fires seems to be the best way of promoting survival of the understorey plant species. It would also provide the usual benefits of allowing animals and birds to escape and the reduced fire intensity is less likely to ignite larger logs which are essential for macrofungal biodiversity.

Plate 44. A vehicle and horse trail penetrating the eucalypt forest on the western side of Mt Coot-tha Forest. Some exotic grasses can be seen amongst the trees.

Plate 45. Exotic grasses; this dense cover has now displaced the native species. When dry, this tall grass cover provides excellent an excellent ignition source for forest fires.

Plate 46. A heavily infested weed gully at Simpson's Falls. Although this is periodically weeded by volunteers, it is again completely overgrown with exotic species.

Plate 47. A vine thicket. The central tree is festooned with lianas which hang from the branches. A second heavily infested tree can be seen at the right of the central tree.

Tinchi Tamba Wetlands

Size: 371 Ha. **Location**: 27° 21'S; 153° 03'E

Vegetation

The park is very similar to the Boondall Wetlands in that it contains a mixture of open woodland, grassland, claypans (Plate 50) and mangrove swamps (*Avicennia* sp.) (Plate 48). The woodlands contain species of *Eucalyptus*, *Allocasuarina* and paperbarks (*Melaleuca*) however for much of the park woodland, the dominant tree is the eucalypt (Plate 49). Interspersed in this woodland are species of wattle (*Acacia*) and fig (*Ficus*). *Cupaniopsis* is present and another dry rainforest taxon, *Jagera* is also to be found. As occurs in the Boondall Wetlands, bats constantly inoculate this park with seeds in their droppings.

Aspect and Features

The area is flat with tidal inlets penetrating into the grassland areas and fringed by extensive mangrove thickets, however this park seems slightly higher than the Boondall Wetlands, although this is somewhat subjective. Parts of the park are subject to periodic tidal flooding. The park is fringed by the Pine River and Bald Hills Creek on the northern and eastern sides, while the Gateway Arterial and Bruce Highway bound the southern and western sides. Most of the park is not penetrated by any trails or walking paths.

Walking Paths

There is a single, relatively short walking track loop centered on the car park entrance. The loop track has a very hard surface and in the swamp areas becomes a raised board walk. There seems little reason to leave this designated track and there was no noticeable evidence of any "unauthorised" shortcut tracks.

Fire

This particular park does have some very old fire residues of charred branches, however their appearance suggests that either fire rarely occurs or is moderately frequent but of low intensity..

Weeds

This park has only a minor weed problem in the areas with public access. Weeds identified include: "mother of millions", *Opuntia*(prickly pear – single plant), asparagus fern and khaki weed. It is very difficult to speculate what is different between this park and Boondall wetlands because they are only a few kilometres distant and both contain large areas of fringing mangroves and eucalypt/paperbark swamps. It is possible that Tinchi Tamba's relative isolation from large population and traffic flows helps in its weed suppression and also reduces the incidence of fire instigated by reckless actions.

Sensitivity to Climate Change

The comments made on the Boondall Wetlands seem equally applicable to Tinchi Tamba. It is very possible that this park may be quite sensitive as a whole to climatic change. Some aspects to consider are the possibility of rising sealevels (with consequent submersion of parts of the park), saline water tables and in addition, even if sea levels do not rise, very long dry periods may alter the water balance and nutrient dynamics within the park soils. Some of these soils break down under these conditions to release heavy metals and acid compounds which can be highly damaging to the plants and even render parts of the park virtually sterile. For the moment, thought should be given to reducing the fire impacts in the lower western end, even if only to strip burn along the arterial road edges.

General Comments

Like Boondall Wetlands, the park contains some pure stands of *Allocasuarina*. These are of immense interest for two reasons: any mycorrhizal taxa that are found are specific on those trees and second, the taxa will be somewhat salt tolerant, an aspect that is currently little investigated for the Australian macrofungi in general.

Plate 48. A pedestrian boardwalk allowing access to a small portion of the mangrove swamps.

Plate 49. A section of the park woodland showing casuarinas and paperbarks with the eucalypts as the dominant trees. The forest floor is largely free of weeds.

Plate 50. A claypan area in Tinchi Tamba wetlands with fringing mangroves.

Toohey Forest

Size: 532Ha. **Location**: 27° 32′S; 153° 02′E.

Vegetation

The western section of the park contains a mixture of open eucalypt woodland and forest with an understory of native species (Plates 51 & 52). The dominants are mostly various species of *Eucalyptus*, however some parts exhibit dense stands of *Allocasuarina*, and these can be dominant over small areas. The understory displays a very good diversity of the usual taxa including: *Allocasuarina*, *Alphitonia*, *Acacia*, *Hovea*, *Dianella*, *Jacksonia*, *Pultenaea*, *Pteridium*, *Xanthorrhoea* and *Leptospermum*. The eucalypt-casuarina mixture is exceptionally good in some areas and this is one of the best vegetational mixes for producing high macrofungal biodiversity in the mycorrhizal taxa. Much of the area still retains a good ground cover of litter and native grass species and the overall state of the park seems remarkably good for its vegetational type. The eastern part of the park is centred on Mt Gravatt and it contains some true eucalypt forest (eg. *Eucalyptus planchoniana*, *E. grandis*, *E. umbra* ssp. *carnea*) with an understory of *Acacia* and *Allocasuarina*, especially on those parts with red-yellow podzolic soils. There is also some very low near-heath complex (Plate 53) on very shallow sandstone soils – principally stunted eucalypts and casuarinas. In the area of the forest near the Griffith University Nathan campus, there are some examples of closed canopy, wet eucalypt forest with vine thickets and dense growths of *Smilax*, a typical rainforest creeper. These thickets have a dense fern layer at ground level and produce deep litter (Plate 54). The forest is mostly eucalypts and paperbarks, but there are occasional rainforest taxa (not identified), particularly in the vicinity of Mimosa Creek. The surrounding dry eucalypt woodland/forest has a dense understory of various shrubs/small trees including: *Pultenaea*, *Allocasuarina*, *Acacia*, *Banksia*, *Alphitonia*, *Hovea* and *Xanthorrhoea johnsonii*.

Aspect and Features

The western side is composed of low conglomerate and sandstone ridges with associated shale inclusions. In this respect it is similar to Karawatha in that it contains generally shallow, stony, poor sandy soils. It is also well drained. The slopes are usually gentle but there are some steep ones on the southern side of the Park. Sandstone and conglomerate bedrocks are exposed on the top of the ridges.

Toohey Road runs through the western part of the Park, whilst the eastern portion is bounded by the Pacific Motorway and Griffith University Mt Gravatt campus (47Ha). To the east of this campus is the Mount Gravatt Outlook Reserve (87Ha) which is bounded by Logan Road to the east, and by urban development to the north and south. Tarragindi lies to the north of Toohey Forest Park (222Ha), and Griffith University Nathan campus (176Ha) to the south.

Four creek systems originate, or are fed by, drainage lines created by the Park's terrain. The eastern headwaters of Bulimba Creek are in the southern section of the forest, courtesy of Mimosa Creek, and this area is characterised by some gullies with moderately sloping banks. To the north-east of Mt Gravatt, the drainage also feeds into Bulimba Creek. Norman Creek is fed, in part, by drainage from the north of the Park, and Rocky Waterholes Creek lies to the southwest.

Walking Paths

There is a very extensive walking track system and parts of it have a bitumen surface. Cyclists (non-motorized) are permitted and the bitumen surfaces ensure little damage is done. The bitumen paths encourage walkers to stay on these prepared surfaces simply because the walking is so much easier. This means that soil compaction, seed dispersal and soil pathogen spread is minimized. The tracks also give very good access for fire control. The hard sandy soils produce very solid and durable track surfaces where bitumen has not been used and there was very little evidence of any track surface damage. Some "unauthorized man-made trails" are present, but these are few and seem limited to the "short-cut" type. There seems to be little evidence of large scale wandering through the park and pedestrians seem content generally to remain on the constructed paths. Dogs on leashes are also permitted. Paths in the southern section are well maintained and often have a bitumen surface, especially where there is heavy pedestrian traffic near Griffith University.

Fire

The evidence of fire is seen all over the park and appears to be of the mosaic type rather than a fierce overall and destructive burn and apart from casuarinas having some difficulty to regenerate, there seems to be plenty of evidence that the park recovers well. This type of dry open bushland is very well fire adapted and low intensity fires have little effect. The low intensity of the previous fires has also left considerable numbers of fallen logs and litter is now becoming abundant again. Litter depths comparable to those recorded for Karawatha Park are now occurring.

Weeds

Much of the western side of the park is remarkably free of weed species – possibly due to the drier and poorer soils. Creeping lantana is present as a prostrate ground cover in some areas and *Ochna* and other garden escapees such as *Melaleuca* are occasional. The Mt Gravatt section has a number of ephemeral weeds present, but other infestations noted are asparagus fern, creeping lantana and some exotic grasses. Garden escapes are likely to be common nearer the house sites bordering the park.

Sensitivity to Climate Change

Given the characteristics of the natural vegetation, with most, if not all of the current taxa well adapted to long dry periods, it is difficult to conclude that climate change will impact markedly on this park other than to increase the number of fires. However a practice of mosaic burning at regular intervals will minimise this problem.

General Comments

The general concept here is to maintain "as is". Mosaic burning to reduce both fire intensity and the potential for local arson is probably the best strategy. Existing conditions in both this park and Karawatha seem to indicate that if climate change raises temperatures and produces longer dry periods, then weeds will find it increasingly difficult to survive and spread.

Plate 51. Western woodland showing the open structure, the bitumen-surfaced path and the weed free understory.

Plate 52. A sample of the eucalypt woodland/forest at the western end showing the sandstone outcrops and very open litter and grass understory.

Plate 53. A portion of the eastern/Mt Gravatt section of the park showing stunted eucalypts and casuarinas on a poor, shallow sandstone soil outcrop.

Plate 54. A vine thicket in the southern end of the park showing the dense understory and the fern layers.