Arboreal Lichen Distribution on Native and Introduced Trees along a Climate Gradient in South Australia

Van Vuong Le
M.Sc., Sunchon National University, Korea
B.Sc., Thai Nguyen University, Vietnam
B.A., Hanoi Open University, Vietnam

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South Australia
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DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Van Vuong Le

LIST OF ACRONYMS

ADS:	Australia Development Scholarship
AIDS:	Acquired immune deficiency syndrome
BoM:	Bureau of Meteorology
CSIRO:	Commonwealth Scientific and Industrial Research Organisation
DBH:	Diameter at the Breast Height
DJF:	December, January, February
Eo:	Evaporation
HIV:	Human immunodeficiency virus
IUCN:	International Union for Conservation of Nature
JJA:	June, July, August
SPSS:	Statistical Package for the Social Sciences

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ABSTRACT

Lichens are under-researched organisms in Australia, and ecological studies that have examined lichens in the context of environmental parameters are rare in all states with the exception of Tasmania. In South Australia, there have been extremely few ecological studies of lichens, none of which have focused on epiphytic lichens on trees. The paucity of research on lichens in Australia poses not only ecological questions but raises conservation concerns.

This study address some of the knowledge gaps related to the issues outlined above through three research questions and a further line of investigation. The questions are: 1) what are the relationships between epiphytic lichens and trees as substrates in the Adelaide Hills, Mid North and Southern Flinders regions of South Australia? 2) what are the relationships between epiphytic lichens and climate in the Adelaide Hills, Mid North and Southern Flinders regions of South Australia? and 3) Does the occurrence of lichens differ between native and introduced trees? The additional line of investigation analysed the threats to, and conservation status of, lichens in Australia, with specific reference to South Australia.

Five species of corticolous macrolichens — *Xanthoria parietina*, the *Caloplaca holocarpa* group, *Physica aipolia*, *Lecidella elaeochroma* and Chrysothrix *xanthina* – were found on 621 trees in 37 study sites situated along climate

gradients in the Adelaide Hills, Mid North and Southern Flinders Ranges regions of South Australia: 254 had corticolous trunk lichens. Lichen species richness per tree ranged from one to three. No follicolous lichens were found.

Statistically significant evidence (Yates χ^2 and Fisher's Exact tests applied to contingency tables) showed that the probability of lichens growing on introduced trees is higher than it is for lichens growing on species native to the Australian mainland. This aspect of lichen occurrence has not been investigated before to the author's knowledge and is a potentially very important finding that needs further research.

Lichens appeared to be relatively independent of tree diameter and height, with the resulting inference being that lichen occurrence is independent of tree age for all tree species sampled. This was also the case for lichens growing on trees of the *Callistemon* and *Fraxinus* genera and *Eucalyptus torquata.*

A weakly positive but statistically significant correlation indicates lichen cover increased as bark became less acidic. Lichens were rare on bark with pH <4.5. The association between lichen occurrence and bark roughness was weakly negative, but again statistically significant. Bark shedding was strongly related to lichen occurrence as indicated by Yates χ^2 and Fisher's Exact tests. There was a clear preference for lichens to establish on stable bark surfaces.

Statistically significant differences in lichen cover were found between the north, east, south and west aspects*. Post-hoc* Dunn's tests showed that the

most frequently occurring pair of significantly different aspects was north and south. This stresses the importance of incident solar radiation and the relative humidity of the trunk microclimate in relation to lichen growth.

The occurrences of trunk and canopy lichens were significantly different. Approximately three-quarters of trees either had lichens on their trunks and in their canopies, or no canopy or trunk lichens. But 14.8% of trees only had canopy lichens; these trees mainly occurred at intermediate rainfall sites. The inference drawn was that lichens begin to establish at an atmospheric humidity threshold that is lower than that required for trunk lichens on the same trees.

In terms of regional-scale climate-lichen relationships, *X. parietina* frequency on all trees, was found to increase with increasing annual, summer and winter precipitation; decreasing annual, summer and winter temperatures; and increasing annual, summer and winter evaporation. These results are intuitive and generally fit existing ecological theory.

The most important threat to lichens in the study area is climate change, with changes in habitat, fire and air pollution being of secondary or local importance. Schedules 7, 8 and 9 of the South Australia National Parks and Wildlife Act do not list lichens in their conservation categories. However, the long-term conservation strategy for the state provides for non-vascular plant conservation. To bring the lichen element of this strategy to fruition, more lichen research needs to be conducted in the state and awareness of lichens needs to be raised through formal and non-formal education.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Nash (2008) defined lichens as "…symbiotic organisms in which fungi and algae and/or cyanobacteria form an intimate biological union." The algal partners are members of the plant kingdom, while the fungi are members of fungi kingdom. Cyanobacteria belong to yet another biological kingdom – bacteria (Ruggiero *et al.*, 2015). However, most lichens do not look like commonly found fungi, nor do they look like higher plants. They are puzzling to the general public, and few people know their roles in nature nor the uses people make of them. This lack of knowledge became apparent during my fieldwork in South Australia, as a succession of people approached me and asked questions like "What are those things you are collecting?" and "Do they harm the trees?".

Lichens grow on many substrates, e.g., trees, leaves, soil, rock, roof tiles, power cables and even the doors of abandoned cars. Most are terrestrial, though a few occur in freshwater streams (e.g., *Peltigera hydrothyria*) and some occur in the intertidal zone (e.g., *Lichina* spp. and the *Verrucaria maura* group) (Wirth, 1995). They vary in size from <1mm^2 (microlichens) to long, pendulous lichens that hang from tree branches and can exceed two meters in length. They can be long-lived − some have been found to be more than a thousand years old − and, unsurprisingly, they can grow imperceptibly slowly at rates of less than a millimetre per year (Nash, 2008).

Estimates of the number of species of lichens vary considerably, and that in itself is an indication of the lack of knowledge about lichens even amongst scientists. The International Union for Conservation of Nature (2017) estimated that there are between 10,000 and 17,000 lichen species. Nash (2008) provided a similar estimate of 13,500-17,000, while earlier Hale (1974) and Filson and Rogers (1979) put the number at around 20,000. The Field Museum in Chicago estimated the number of fungi and lichen species at between 750,000 and 1.5 million (McCarthy, 2013). Very recently, Lumbsch (2017) listed 100 new species from 37 different countries. His publication highlights the largely undocumented diversity of lichens.

Lichens are important integral components of ecosystems. They can be pioneer species in the early stages of ecosystem succession on rock and soil surfaces, e.g., on newly exposed rock, glacial moraine and in deserts. Lichens on tree trunks and branches affect stemflow – an important component of the hydrological cycle in forest ecosystems. They absorb chemicals from the atmosphere and therefore are also important in biogeochemical cycling. Lichens growing in the northern tundra are a key element of the food chain as they are the main food for reindeer. Some of these properties are exploited by environmental scientists who use lichens to date glacial retreat and monitor environmental pollution and climate change.

Lichens are also important locally to various groups of people around the world. For example, they are used as traditional medicines to cure lung disease and as a liver detoxificant. Scientists have also discovered that some lichens may have roles in curing HIV and cancer (Nash, 2008). Other traditional uses are as a fabric dye and an herbal tea. Extracts from lichens are used commercially in making perfume. Some lichens are used in food processing, particularly bread making, as they can prevent food from rotting.

Lichen research is relatively well developed in northern and western European countries, North America, China, South Korea as exemplified by, for example, Hale (1974); M.R.D. Seaward (1977); Hawksworth and Hill (1984); Kantvilas and Jarman (1988); Esseen *et al.* (1996); Wolseley and Aguirre-Hudson (1997); Eldridge (1999); G. E. Insarov *et al.* (1999); Komposch and Hafellner (1999); Boudreault *et al.* (2000); van Herk (2001); Asta *et al.* (2002); Asta *et al.* (2008); Pearson and Dawson (2003); Snäll *et al.* (2003); Nash (2008); Cobanoglu and Sevgi (2009); Fritz *et al.* (2009); Li *et al.* (2013); Nascimbene *et al.* (2013); Rosabal *et al.* (2010); Nascimbene and Marini (2015); Kiebacher *et al.* (2016).

Lichen research is generally less well developed in Australia than the regions listed above. In South Australia there has been less research on lichens than in many other Australian states, and few studies that have been conducted are restricted to lichens growing on rocks and those that form soil crusts (Filson & Rogers, 1979). While epiphytic lichens growing on trees have been researched in Queensland (Rogers, 1995) and Tasmania (Jarman *et al.*, 1984; F. Duncan & Brown, 1985; Brown, 1988), this thesis will be the first published work on epiphytic lichens in South Australia. Further importance can be attached to the last sentence because the widespread clearance of native forests and woodlands throughout Australia since European settlement in the late 18th and early 19th centuries has severely depleted habitat availability for epiphytic lichens. It is a relatively recent and ongoing issue in South Australia where unauthorised tree and bush clearance was not made illegal until the Native Vegetation Act of South Australia was passed in 1995. However, bush clearance can still take place if it is accompanied by a significant environmental benefit (Australian institute of Criminology, 2014). Consequently, arboreal lichens have suffered from significant habitat loss. Offset against the loss of woodland since European settlement began in the state in 1836 have been municipal and garden plantings of trees that are not native to Australia, or which have been introduced from other biomes and ecosystems found in other parts of Australia.

Regardless of whether trees are native to the region studied in this research, or have been introduced from elsewhere, there are few records of lichens on trees in South Australia. Moreover, there has been no systematic study of epiphytic lichens in South Australia. This is the knowledge gap that I will explore in this thesis by focussing on the relationships between the occurrence of epiphytic lichens and bark properties, and with climate; and whether the frequency of lichen occurrence varies between native and introduced trees. In summary, by undertaking this research I will investigate a neglected area of environmental biogeography in Australia.

1.2 Research aims, objectives and questions

This research project focuses on epiphytic lichens in reserves[1] and municipal plantings in the Adelaide Hills, Mid North and Southern Flinders regions of South Australia.[2] The overall aims are to survey the environmental biogeography of epiphytic lichens; research key aspects of lichen autecology such as the interactions between lichens and trees as substrates, and between lichen and climate; and to ascertain if there are differences in lichen occurrence between native and introduced trees.

In order to research these aims, three broad research questions were established:

1. What are the relationships between epiphytic lichens and trees as substrates in the Adelaide Hills, Mid North and Southern Flinders regions of South Australia?
2. What are the relationships between epiphytic lichens and climate in the Adelaide Hills, Mid North and Southern Flinders regions of South Australia?
3. Does the occurrence of lichens differ between native and introduced trees?

A further line of investigation, though not a research question in a formal sense, was to analyse the threats to, and conservation status of, lichens in Australia, with specific reference to South Australia.

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[1] Reserve is an Australian term equating to a park or municipal garden in Europe and North America. It can also be used to describe a sports field in suburban and rural areas.

[2] The terms Adelaide Hills and Mid North are used in this thesis (and defined in Chapter 3). However, the area also includes part of the southern Flinders Ranges. An alternative name for the Adelaide Hills is the Mount Lofty Ranges.

1.3 Researcher positionality statement

I am a Vietnamese scientist working for the Western Highlands Agro-Forestry Science and Technical Institute in Buon Ma Thuot City. My PhD was funded an Australian Government Department of Foreign Affairs and Trade (DFAT) Scholarship. My undergraduate degrees were in Agriculture and English. My first exposure to lichens came when I studied under Professor Jae-Seoun Hur at Sunchon National University, South Korea for my Master’s on the induction of soil microbial activity by lichen colonisation on an abandoned coalmine waste dump.

1.4 Thesis structure

This thesis is divided into seven chapters. The first chapter presents general information about the entire thesis. Most importantly, it identifies the overarching aims and research questions, and stresses the importance of the research and the scientific contribution it will make. Chapter Two provides information on the available literature and identifies some of the gaps in knowledge that this thesis addresses. The study area is also briefly described in the chapter. Chapter Three covers research design, the sampling plan, and the methods used to collect and analyse the lichens sampled. Chapter Four examines the relationships between tree properties and epiphytic lichens across the area studied. Chapter Five examines the relationships between climate and epiphytic lichens at different geographical scales in the study area. Chapter Six examines the threats to lichens, with special reference to South

Australia and discusses options for lichen conservation. Chapter Seven summarises the findings of this research.

The thesis conforms to the guidelines for the College of Science and Engineering at Flinders University in that it should contain between one and three pieces of work that could be published. These do not have to be published by the time the thesis is examined. In consultation with my supervisors I am proposing to submit three publications to journals as follows:

- An analysis of the relationships between corticolous lichens and climate, for *Austral Ecology* or *The Lichenologist*. This will mainly be based on the research reported in Chapter Five.
- An analysis of the relationships between corticolous lichens, bark properties and the differences in their distribution on trunks and in crowns, for *The Lichenologist* or *The Bryologist*. This will mainly be based on the research reported in Chapter Four.
- A paper that analyses the differences between lichen occurrence on native and introduced trees (based on work reported in Chapter Four) and the status of tree lichens in South Australia (which is based on the entire thesis, but specifically some material from Chapter Six). This will be submitted to *Pacific Conservation Reviews* or *Austral Ecology*.

CHAPTER TWO

THE BIOGEOGRAPHY AND AUTECOLOGY OF EPIPHYTIC LICHENS

2.1 Introduction

This chapter synthesises the key research literature related to the present study and gaps in current knowledge are identified. After a general introduction to lichens and a concise history of lichen research, which focuses on South Australia, there are three main components to this chapter:

- a comparison of lichens by substrate type;
- a discussion focused on the autecology of corticolous lichens; and
- a review of material on threats to, and conservation, of lichens.

2.2 Lichens

Lichens appeared in the geological record about 400 million years B.P. during the Early Devonian (Taylor *et al.*, 1995). They are symbiotic organisms, usually composed of a fungal partner, the mycobiont, and one or more photosynthetic partners, the photobiont, which is most often a green algae or a cyanobacterium (Hale, 1983; Hawksworth & Hill, 1984; Pinokiyo *et al.*, 2006; Nash, 2008). They have a number of morphological characteristics and colonise a wide range of inorganic and organic substrates. Both morphology and substrate type (see Section 2.3 for details) have been used to identify and classify lichens. The principal morphologies of lichens are crustose (crust like); squamous (tightly clustered and slightly flattened, pebble like); foliose (leaf like with flat sheets that are not tightly bound); and fruticose (free standing branching tubes). All lichens have a similar internal morphology consisting of the outer surface called the cortex; the symbiont layer consisting of algal cells; and below that the medulla of loosely woven fungal filaments.

The relationship between the fungal and algal or cyanobacterial partners ranges from mutualism to controlled parasitism. It has been argued that lichens are the most successful form of symbiosis (M.R.D. Seaward, 1997), in which the fungus gains a carbon source while the photobionts obtain protection, nutrients and water. Lichens can be found in a very wide range of habitats in biomes that extend from Polar regions to deserts and rainforests (e.g. Henssen & Jahns, 1974; M.R.D. Seaward, 1977; Hale, 1983; Hawksworth & Hill, 1984; Kershaw, 1985; Nash, 1996; M. Seaward, 2000; Brodo *et al.*, 2001). It is estimated that around 8% of the terrestrial surface of the earth is covered by lichen-dominated vegetation (Chen *et al.*, 2000).

Lichen thalli absorb all their nutritional requirements from the air and the water they come into contact with. For example, water may be absorbed from the atmosphere, from dew, rainfall, stemflow on trees and runoff in the case of lichens on rock and soil surfaces. When water is absorbed, the chemicals in solution are also absorbed by the lichen. This is the main pathway through which lichens obtain nutrients. However, nutrients dissolved in rainwater are usually found in very low concentrations, as are the concentrations in the other water sources identified earlier. Related to this is the fact that lichens play an important functional role in forest ecology by being involved in water and nutrient cycling.

In response to these low concentrations of nutrients, lichens have evolved highly effective but indiscriminate mechanisms for the absorption of ions in solution. A by-product of these indiscriminate mechanisms is that airborne pollutants are also absorbed, with devastating results in many cases. However, this does make them among the most sensitive of all organisms to air pollution, and therefore excellent bioindicators (CSIRO, 1999).

Lichens have important functional ecological roles. For example, they contribute to biodiversity, are implicit in nutrient cycling, are effective in soil amelioration and provide animal habitats. Their importance is underlined by the fact that vegetation surveys in Washington state (USA) now include cryptogams, a structural and functional vegetation mapping term which includes lichens (Ellenberg & Mueller-Dombois, 1974) thereby providing recognition of their importance as forest health indicators (Glew, 2000).

2.3 A concise history of lichen research in South Australia

The Swedish doctor, Erik Acharius, was the first person to study lichen morphology and he is regarded as the father of lichenology (Hale, 1974). In 1803, he introduced the terms soredia, isidia and cepholodia to describe unique lichen structures. By 1866 the well-known German mycologist Anton de Bary was able to write an accurate account of the morphology of lichens that can still be used as a reference today (Bary, 1866). A slightly later work, Annie Lorraine Smith's *Lichens*, provides an early yet exhaustive description of lichen morphology (Smith, 1921).

However, even before Acharius' work, the first study of lichens in Australia had taken place when in 1791, when Jacques-Julien de Labillardière accompanied Bruni d'Entrecasteaux on his voyage to the South Seas to search for La

Pérouse. During the expedition, de Labillardière collected lichens and many other plant specimens in Tasmania, close to where Hobart is now sited (CSIRO, 1999). On returning to France he published the second volume of his findings "*Novae Hollandiae Plantarum Specimen".* Within this book he illustrated the lichen species *Baeomyces reteporus*, which he classified as an algae; however it was later found to be a coral lichen and reclassified as such (ABC Radio Hobart, 2017).

However, published systematic studies of lichens in South Australia are limited (Rogers & Lange, 1971; Rogers, 1972; Rogers & Lange, 1972; Filson & Rogers, 1979; Department for Environment and Heritage, 2017). Despite the scarcity of publications there are approximately 1,000 lichen specimens in the South Australian State Museum some of which can be accessed through the National Plant Database. Most are under-researched and may need reclassification. The key publication is the book entitled *Lichens of South Australia* (Filson & Rogers, 1979). Additionally, Rogers has published individually and jointly on terricolous lichens (Rogers & Lange, 1971; Rogers, 1972; Rogers & Lange, 1972). As far as I have ascertained there has been no peer reviewed publication which has focused solely on epiphytic lichens in South Australia. Therefore, tackling the lack of research on epiphytic lichens in South Australia is an opportunity to be exploited in this research thesis.

2.4 Lichen substrates

According to Skye (1979), lichens occur in all terrestrial biomes, from the tropics to the Arctic tundra and ice-free areas of Antarctica, and from sea level to the tops of the highest mountains. Several species are widespread and have cosmopolitan distributions, while others are far more restricted; though given that lichens are relatively under-researched it is possible that the geographical ranges of some lichens are greater than reported.

Lichens are often categorised by the substrates that they grow on. A few lichens are confined to a single type of substrate, while others grow on almost any surface. The main substrates on which lichens grow include leaves (these are called foliicolous lichens); bark (corticolous lichens); wood (lignicolous lichens); rocks (saxicolous lichens); soils (terricolous lichens); and even glass (vitricolous lichens). They also occur on other artificial materials like roof tiles, bricks, walls, roadways and concrete. Less commonly, lichens grow on metallic surfaces such as galvanised iron roofs, electricity transmission cables and abandoned cars. They have also been found growing on leather, glass, bones, cardboard and even discarded nylon stockings in old rubbish tips (CSIRO, 1999). They can establish on these diverse surfaces because they do not rely on the substrate for anything more than a place to attach.

Lichens which grow on vegetation are called epiphytic lichens. Worldwide, the vast majority of these are corticolous lichens. The exception being in the humid tropics where there are also vast numbers of foliicolous lichens. Corticolous lichens occur on all woody parts of trees and shrubs, twigs, branches and trunks, and are the focus of the research in this thesis.

2.4.1 Foliicolous lichens

Foliicolous lichens are the epiphytic lichens which grow on the surfaces of leaves of vascular plants. They may be the most geographically restricted group of lichens since they are largely confined to the tropical rainforest biome. Leaf surfaces host many other organisms, including bryophytes, algae, fungi, bacteria and invertebrates.

Professor Robert Lücking of Chicago’s Field Museum, an expert on foliicolous lichens, stated that lichens on leaves can be seen as model organisms through the lens of tropical forest ecology and has produced several protocols for research into them (Lücking, 2008). More than 800 species of foliicolous lichens are known (Kirschbaum & Windisch, 1986), but as will be seen later in this chapter most estimates of lichen numbers in an area or biome are simply minimum numbers that are waiting to be increased as further inventories are made. Nonetheless, because the majority of foliicolous lichens have been found in the humid tropics, it is likely that lichen diversity in the humid tropics is higher than in other biomes. Singh and Pinokiyo (2008), for instance, noted very high lichen diversity in eastern India.

New species of foliicolous lichens are still being discovered. Examples of recent discoveries are those of Yeshitela *et al.* (2009), who found two new foliicolous lichen species in Ethiopia and Kenya – *Aspidothelium hirsutum* and *Caprettia goderei*; Farkas *et al.* (2012), who identified a new species from Brazil – *Calopadia erythrocephala;* and Singh and Pinokiyo (2008), who studied foliicolous lichens in eastern India and found two new species –

Mazosia lueckingii and *Sporopodium awasthi-anum*. However, discoveries are not just being made in the humid tropics. South Korea is a mainly temperate country and therefore foliicolous lichens do not have a prominent place in its lichen flora but Jayalal *et al.* (2013) recently found four leaf lichens that are endemic to the country: *Strigula concreta, S. macrocarpa, S. melanobapha,* and *S. subelegans*: though like most of the foliicolous lichens in neighbouring southern Japan, these new species were discovered on Jeju Island in the south of the peninsula.

Many researchers have studied lichen growth on leaves. Linkola (1918) and Paulson (1918) measured the growth of lichens on leaves and similar work is still ongoing. Armstrong and Bradwell (2011) showed that the thalli of foliose lichens grow by radial extension at the perimeter throughout their life, and that several foliose lichens can survive for 30 to 60 years.

Several authors have studied the relationships between foliicolous lichens and environmental factors. Anthony *et al.* (2002) examined the shade acclimation of leaves in a rainforest that was colonized by epiphytic lichens and found that on individual leaves lichens can account for over 50% of the surface of the leaf, with lichens always occurring on the upper surfaces of leaves. Studying lichens on leaves of the rainforest shrub, *Capparis arborea*, on Mt. Glorious in Queensland, Rogers (1995) showed that lichen succession was determined by the increasing age of leaves. Interestingly this chronosequence was different for another shrub in the same forest, *Wilkiea macrophylla*, which led Rogers to conclude that “lichen succession is not a simple time-dependent sequence on this host plant species”.

2.4.2 Corticolous lichens

Corticolous lichens – the focus of the present research – are the other main type of epiphytic lichen. Lichen on tree bark is completely harmless to the tree itself. The rhizines, which are similar to roots but do not extract nutrients (Skye, 1979), allow lichens to attach themselves to the tree but they do not penetrate deeply enough to harm it in any way (Rhoades, 2014). Like all lichens, corticolous lichens acquire their nutrients through their thalli (Skye, 1979).

Esslinger (2006) stated that lichens are very important components of ecosystems and they account for a huge number of species within many ecosystems. In North America and Mexico alone, for example, there are over 7,700 species showing that the numbers of corticolous lichens in temperate forest can be very high. Bolliger *et al.* (2007) only detected six epiphytic lichens across a 41,000km^2 study area in Switzerland, while corticolous lichen diversity is very high in tropical forests, as is also the case for foliicolous lichens. Cáceres *et al.* (2007) found that the total number of bark lichens in the Atlantic rain forest in northeastern Brazil was one of the highest which had been measured at that time. They found 150 lichen species on 47 mature trees in the area studied. However, this is lower than the numbers found by Komposch and Hafellner (1999), Komposch and Hafellner (2000), Komposch and Hafellner (2002) and Komposch and Hafellner (2003) in Venezuela, and Aptroot (1997) in Papua New Guinea, with 250 and 173 corticolous lichen species being recorded respectively.

The numbers of lichen found in studies from temperate areas vary considerably. A study In South Korea only found 15 lichen species at 14 sites however, the number of the specimens across all 14 sites was quite high at 600 individuals (Hur, Harada, Oh*, et al.*, 2004). Giordani (2007) recorded 190 lichen species at 165 sites in Italy with mean annual precipitation values ranging from 950-1,800mm; and Fanning *et al.* (2007) found 194 species of corticolous lichens in the Great Smoky Mountains National Park in the Appalachians. Culberson (1955) found the number of lichen species per forest stand declined with increasing latitude in Wisconsin. Cameron *et al.* (2011) noted that *Erioderma mollissimum* is a rare cyanolichen in Canada because it is threatened by a range of human agents. Yet, spatial modelling indicated that although records only exist in a small part of Newfoundland, the suitable geographical range for the species on the island is far greater.

Like foliicolous lichens, new corticolous lichen species and associations are still being discovered. What is surprising about some of these discoveries is that they are from well-researched European countries. Most surprising is that as late as the mid-1960s, Boom (1996) recorded the first corticolous lichens in Belgium, growing mainly on *Acer campestre.* Crisan (2010) identified three phytosociological associations of corticolous lichens — *Physcietum ascendentis, Parmelietum acetabuli* and *Parmelietum caperatae* – in oak, beech, hornbeam-beech, and fir-beech forests in the Padurea Craiului Mountains in Romania.

Of course, it is less surprising that many new species are still being discovered in many humid tropical countries. Lugo-Fuenmayor (2013) found 85 corticolous lichen species (in 40 genera and 25 families) on 60 trees at six sites between 0-1,400 m.a.s.l on the northern slopes of the Sierra de San Luis in Venezuela. This was the first collection in this area and as a result 46 species had their geographical ranges extended into Venezuela. She sampled lichens on tree trunks between ground level and 1.3m and found corticolous lichens with crustose thalli accounted for 70% of individuals. Quedensley and Pérez (2011) found a new corticolous lichen — *Ramalina mahoneyi* – in a cloud forest in western Guatemala. Though similar to *R. celastri* in morphology, the thallus is grey-blue and it is generally smaller. Rosabal *et al.* (2012) found that 51 of the 74 species they recorded in the montane rainforest of western Cuba were new records for that country. Two new lichen species were recently discovered in Australia: *Ramboldia atromarginata* and *R. greeniana*. The first is a corticolous lichen found in wet sclerophyll forests in Victoria, and the latter is a saxicolous species from upland areas in Tasmania (Kantvilas, 2016).

The studies from Switzerland and South Korea indicate that outside the tropics very few lichen species may be found over large areas. Therefore, it was anticipated that the number of species that will be found in the arid and semi-arid and dry sub-humid climates covered by this research will be low (in fact only 5 macrolichens were found an area of 45,000 km^{2,} see Chapter Four). As will be pointed out later this is similar to the number of epiphytic lichens found by Bolliger *et al.* (2007) in Switzerland in 2007 — six in area of 41,000 km^2.

The relationships between corticolous lichens and environmental parameters will be discussed in detail in Section 2.5, and unlike the sections on foliicolous, saxicolous and terricolous lichens.

2.4.3 Saxicolous lichens

Slow-growing saxicolous lichens live on the rocks (Armesto & Contreras, 1977) and in the absence of external perturbations they may develop over extremely long periods. Saxicolous lichens are extreme taxa in the plant kingdom with respect to growth rates and longevity (Armesto & Contreras, 1977). Hensel (1902) wrote that lichens on rock exhibited "…many beautiful colours…" which he assumed were due to the different mineralogy of the rocks on which they grow. For example, he discovered that brown coloured lichens grew on brown coloured rocks. More importantly he also provided evidence of their corrosive and etching effects on rock. Almost a century later, Chen *et al.* (2000) stated that rates of lichen weathering (Viles, 1988) vary between lichen species. This is because of the different effects of physical and chemical processes on rock surfaces. Physical weathering takes place through the expansion and contraction of organic and inorganic salts in the presence of lichen activity, while the chemical processes dissolve minerals. As a result, many rock-forming minerals exhibit surface corrosion due to lichen growth.

New saxicolous lichens and range extensions are still being discovered. For example, a joint Russian and American expedition to eastern Siberia, the Russian Far East and the Seward Peninsula in 1992 and 1993 that focused on saxicolous lichens in the Lecideaceae family, estimated that there are 560 species in the area and many range extensions of existing lichens were discovered (Hertel & Andreev, 2003). Bergamini *et al.* (2005) conducted research in eight European countries situated in six different biogeographic zones (Alpine, Switzerland; Atlantic, Ireland and United Kingdom; Boreal, Finland; Continental, France; Mediterranean, Portugal and Spain; Pannonic, Hungary) and found 768 lichen species belonging to 157 genera. Saxicolous and epiphytic lichens accounted for 60% of the total species richness and 75% of the total genera richness at these sites.

Bjelland (2003) studied four saxicolous lichens – *Fuscidea cyathoides, Ochrolechia tartarea, Ophioparma ventosa* and *Pertusaria coralline* – in coastal Norway and found that the variation in the lichen communities bore little relation to micro-environmental factors. The level of vegetation cover led to the greatest variations in lichen floristic variation. While incident radiation and maritime influences had intermediate levels of influence on lichen variation. Bjelland also noted that the lichen species studied supported the idea that they are able to co-exist in the long term since the distributions of individual species are the result of differences in ecological processes, synergies and dispersal strategies.

Five saxicolous and epiphytic lichens – *Hypogymnia physoides*, *Lecanora muralis, Parmeliopsis ambigua*, *Phaeophyscia orbicularis* and *Platismatia glauca* – were examined to investigate pH dependence on the intake of iron and phosphorus (Paul *et al.*, 2009). They found that pH was the most influential factor. Moreover, pH dependence was found in lichens growing in acidic soils, rocks and trees

Perkins *et al.* (1980) found that the rate at which saxicolous lichens accumulated airborne fluoride near an aluminium plant in North Wales was much slower than the accumulation rates in corticolous lichens, indicating either better trapping efficiency or different rates of key metabolic processes between the lichens. Perkins and Millar (1987) studied saxicolous lichens on different rock and wall substrates and showed that in the saxicolous lichen *Ramalina* sp., although fluoride concentration decreased with distance from an industrial source, it was also affected by the wind direction and level of emission susceptivity. Research by Armstrong (1997) in the same region measured the levels of calcium, copper, manganese, magnesium and zinc in *Xanthoparmelia conspersa* and *Parmelia glabratula* ssp. *fuliginosa* and found that some metallic ion concentrations in the lichens were greater in situations where most runoff accumulated, and that magnesium collected in thalli in greater concentrations than the other ions and that its concentration decreased with thallus size in both species.

Armstrong (1984) studied the impact of bird droppings and uric acid on five saxicolous lichens commonly found where cliff nesting birds were found in the United Kingdom. Bird droppings and uric acid increased radial growth in some species; e.g., *Pamelia conspersa* responded positively to both while *Xanthoria parietina* growth rates only increased in the presence of bird droppings. In contrast, the growth of *Parmelia glabratula* ssp. *fuliginosa* was inhibited in the presence of bird droppings.

Marsh and Timoney (2005) asked the question “How long must saxicolous lichens be immersed to form a waterbody trimline?” in research conducted in northern Canada. Seven common saxicolous lichens were immersed in water for 270 days. The rate of fatality increased after 30 days of immersion, and reached 68% by 90 days and 91% at 180 days. After 270 days all lichens had died, but that the mortality rates varied between species. *Phaeophyscia sciastra* had the lowest mortality while *Xanthoparmelia somloensis* had the highest.

2.4.4 Terricolous lichens

Under the guise of biological soil crusts terricolous lichens have been described as ecosystem engineers in arid and semi-arid habitats (H. T. Root *et al.*, 2012) where they affect soil chemistry, soil stability and vegetation growth (Alexander & Calvo, 1990; Lázaro *et al.*, 2000; Lázaro *et al.*, 2008). Aggregate stability and soil conservation on bare and lichen-rich loess-covered hills in Northern Golestan Province, Iran were compared and it was found that soil aggregate stability increased about threefold in lichen-covered soils because fungal hyphae and polysaccharide excretions bound soil particles together and increased the size of soil aggregates (Ajami & Khormali, 2011). Moreover, bare soils had weak, massive structures; while lichen-covered soils had a crumbly, granular structure with well-separated angular blocks and a high proportion of voids. They concluded excremental pedofeatures were the most common pedofeatures in the lichen-covered soils. Terricolous lichens that colonized a coal mine waste dump site in South Korea, led to elevated levels of soil biological activity compared to soils without lichen colonisation (Hur, Harada, Lim*, et al.*, 2004). However, the influences on terricolous lichen growth are not restricted to soil properties. Guevara *et al.* (2018) argue that global warming will affect lichen-dominated biocrusts by reducing lichen cover, richness and evenness and promoting moss growth.

Apart from these few studies, the role of lichen species composition and diversity is often poorly known in dryland regions; a fact that has been noted in the drylands of the Pacific Northwest of the USA (H. T. Root *et al.*, 2012). There is, however, a body of research on terricolous lichens from Australia. For instance, Eldridge (1999) evaluated the distribution and abundance of soil crust lichens and bryophytes in eastern Australia and showed that the most important factors related to the distribution of species were the presence and intensity of sheet and scarp erosion, soil stability and soil coherence. Rogers and Lange (1971) studied soil crust lichens in South Australia and showed that terricolous lichens were able to stabilise the soil surface, especially in the arid north of the state. The same authors also showed that there is a paucity of information on terricolous lichens in South Australia, a conclusion they drew after evaluating 343 areas, totalling approximately 1 million km^2, in which 227 lichen species were found.

2.5 The autecology of corticolous lichens

2.5.1 Climatic influences

Corticolous lichens occur in all terrestrial bioclimatic zones and they can be seen on many, though not all, tree species. Their growth rates are related to climate parameters such as water and light availability, and humidity. That said, lichen abundance is higher and growth rates are fastest in areas with high relative humidity (Nash, 2008). At the landscape scale, climate (moisture, temperature and evaporation) gradients are likely to be reflected in significant differences in lichen abundance, diversity and growth rates as they capture their water and nutrients from the atmosphere or water that comes in contact with them and their host substrates. Armstrong and Bradwell (2011), for example, noted the importance of moisture availability in influencing foliose lichen growth.

Paterson *et al.* (1983) found that moisture is the most important single factor affecting lichen growth in temperate climates. Though other factors aside from moisture influence lichen distribution, suggesting a more complex multivariate relationship between lichen and climate parameters. High and low temperatures also limit lichen growth, abundance and diversity along altitudinal gradients, which are, in effect, environmental gradients along which temperature varies. However, it is likely that such gradients also reflect differences in moisture availability as well. Ozturk *et al.* (2010) stated that corticolous lichen distribution and lichen amount on beech trees on Ulu Dag Mountain in northwest Turkey are correlated significantly with altitude. Furthermore, the species composition of lichens also varied along the altitudinal gradient. Giordani and Incerti (2008) arrived at similar conclusions while studying climate and epiphytic lichen distributions in Italy. Their findings indicate that lichens are related strongly to both microclimatic and macroclimatic factors, and that atmospheric humidity and rainfall are the main water sources for these organisms. In summary, environmental conditions such as light and moisture availability and substrate play crucial roles in the distribution of lichens along gradients.

2.5.2 Incident radiation and exposure

Cobanoglu and Sevgi (2009) found that the abundance of lichens on the northerly aspects of the trees was greater than that on the southerly aspects in all trunk diameter classes. This finding is in line with earlier studies on lichen-aspect relationships in the northern hemisphere and is related to the interplay of the amounts of incident solar radiation, humidity levels and the amount of corticolous lichen growth. It appears from this study in Turkey that aspect influences lichen growth in arid and semi-arid areas, but this needs the further testing that will be carried out in this thesis. No differences were found between lichen species composition and frequency with trunk aspect in Cuban rainforests (Rosabal *et al.*, 2010), but Rosabal *et al.* (2012) and Rosabal *et al.* (2010) found that lichen occurrence was affected by light penetration into these forests. Trees in the forest interior only had 43 species of lichen, compared to 56 at the forest edge. Twenty-five occurred in both locations. The authors showed that the differences in corticolous lichen cover on trees was due to differences in incident solar radiation.

2.5.3 Tree age and diameter

Johansson *et al.* (2007) surveyed lichen diversity on 143 ash trees ranging from 11 to >140 years in age (ages were estimated from the trunk diameters). The number of lichens on individual trees varied from two to 30. The number of species did not increase on the trees >65 years, although species composition did change with tree age. They argued that the positive relationship between species richness and lichen cover might be compatible with random placement of species. They also found that the lichens that occurred most frequently on older trees had larger spores and thicker thalli than other species, and also that rare species were restricted to old trees. According to Kuusinen and Siitonen (1998) epiphytic lichens in old protected stands of *Picea abies* in southern Finland were found on the trunks of trees >120 years. Some other studies are in general agreement. For example, Berg *et al.* (1994) found that older trees were capable of carrying more lichen species than young trees; Uliczka and Angelstam (1999) showed that epiphytic lichens increased with tree species-tree age associations in Denmark; and Rosabal *et al.* (2013) found that lichen composition was related to tree diameter in Cuban rainforests.

However, other findings are somewhat contradictory. Vinayaka *et al.* (2011) found that 33 of 36 lichen species in the western Ghats in India grew on the trees which had trunk diameters of <25cm and that the number of lichens decreased as trunk diameters increased. Cobanoglu and Sevgi (2009) evaluated the distribution of epiphytic lichens on *Cedrus libani* trees in Antalya Province, Turkey and found that the highest number of species were found on trees with trunks in the 30-40cm diameter class, in comparison to younger (0-15cm, 15-30cm classes) and older (45-60cm and >75cm classes) trees. Wolseley and Aguirre-Hudson (1997) concluded that tropical forests did not exhibit the lichen-tree age relationships that are commonly found in temperate forests.

Sevgi *et al.* (2016) researched the effect of forest habitat on the distribution of lichens in Serif Yuksel Research Forest in Bolu, Turkey using tree species, forest purity, altitude, slope, aspect, tree girth and lichen species using a binary logistic regression analysis. They concluded species and tree girth were the most important explanatory variable parameters. The distribution of lichen genera varied with tree species, and the physical and chemical characteristics changed with trunk diameter. They cited research by Stevenson and Enns (1993) in which the abundance of individual lichen species and their surface areas were strongly correlated with tree diameter.

While studying the distribution and succession of epiphytic lichens on *Picea abies,* Hilmo (1994) observed that tree height and age were the most important parameters in explaining lichen species distribution. Kantvilas and Jarman (2004) found that the extent of lichen habitat increased with tree diameter in Tasmanian forests. Earlier research by the same authors found that *Eucalyptus obliqua* was the preferred substrate for lichens and that *E. obliqua* trees hosted an excellent epiphytic flora (Jarman & Kantvilas, 2001). This led them to concluded that old, tall eucalyptus trees are vital habitats for cryptogams.

Vertical distribution

Fanning *et al.* (2007) examined lichen species richness and vertical distribution of all types of epiphytic lichens on the trunk and canopy strata in Appalachian forests. They showed that more lichen species grew on leaves than on the bark of the Fraser fir (*Abies fraseri*) and Sweet gum (*Liquidamber styraciflua*) but there was no statistical difference amongst ash trees (*Fraxinus* sp.). Foliose lichen richness also varied vertically on *Abies fraseri*, with richness being highest in the lower and middle strata of the canopies. Kiebacher *et al.* (2016) conducted similar research on lichens and bryophytes on tree stems and crowns in sycamore-maple forests in the northern European Alps and found that the number of bryophytes ranged from 13 to 16 and the number of lichens ranged from 25 to 67. In total 42 bryophytes and 104 lichens were listed. A key finding was that 29% and 61% of bryophytes and lichens respectively were recorded in the crown. Culberson (1955) found there was no significance difference between lichen occurrence at the base of trunks and at 1.3m and Rosabal *et al.* (2010) found no differences in vertical distribution of lichens in trees in montane rainforest in eastern Cuba.

2.5.4 Bark properties

Vinayaka *et al.* (2011) found that trees with rough bark had a higher frequency of fruticose and foliose lichens, whereas smooth-barked trees had more crustose lichens. However, Wolseley and Aguirre-Hudson (1997) found that thin smooth-barked trees had more lichens than other bark types in forests in northern Thailand. In addition, lichens on these trees remained as the trees grew and the bark changed to a thick, fire-resistant bark. They also noticed that on some trees that lichens were more frequently encountered above the height of forest fires. Lichens are rarely found in tree species that frequently shed bark, for example many species of *Eucalyptus* (Kantvilas & Jarman, 2004). In earlier research, Culberson (1955) was able to define three tree species-colicolous lichen groups defined on the basis of bark hardness, its water absorbing capacity, and bark pH.

A more detailed study by Cáceres *et al.* (2007) examined lichen phorophyte preferences and area cover with bark properties in corticolous crustose microlichen communities in the Atlantic rain forest of northeastern Brazil. Using bivariate and multivariate regression they found that bark pH, bark shedding, and the density and size of bark lenticels were negatively correlated with phorophyte preferences and area cover, while the presence of milky sap and a 'diffuse site factor' were positively correlated.

Wolseley and Aguirre-Hudson (1997) noted that pH was an important factor in determining lichen distribution in trees with dry bark in a range of forests types in northern Thailand. In addition, that had higher bark pH had richer lichen communities that those with low pH bark. This relationship is similar to that which has been found in cool temperate forests (James *et al.*, 1977; Rogers, 1992), and in tropical rain forests (Rosabal *et al.*, 2013). The latter group of researchers also found that lichen species composition was linked to the level of phenol concentration in tree bark.

2.5.5 Spatial distribution of lichens

In a study of the spatial distribution of epiphytes on aspens (*Populus tremula*) in Sweden, Hedenås *et al.* (2003) hypothesised that distributions would differ between sexually and asexually dispersed species of lichens and bryophytes. To test this hypothesis, they evaluated two sexually dispersed species, the lichen *Collema curtisporum* and the bryophyte *Orthotrichum speciosum,* and three asexually dispersed species, the lichens *C. furfuraceum* and *Leptogium saturninum* and the bryophyte *O. obtusifolium.* They found that dispersal and establishment strategies of each species were more important than environmental factors in determining the local distribution of each species.

While the review of environmental factors affecting the growth and diversity of corticolous lichens has been structured around individual or sets of related variables, in reality these variables compete against each other in determining the lichen community of any tree or part of a tree. Bergamini *et al.* (2005) found that a range of variables, when considered together in multivariate analysis only explained from 0.2-0.41 ($R^2_{adjsuted}$) for microlichens and even less for macrolichens (0.09-0.29, $R^2_{adjsuted}$).

2.6 Threats to lichens and conservation issues

2.6.1 Threats

There are many threats to lichens. In particular, they are extremely sensitive to climate change and air pollution (Nash, 1996; Galun, 1998; Nimis & Martellos, 2001) to the extent that they have been used as air pollution indicators for a number of decades and, more recently, have been proposed as climate change indicators.

Most of the recent literature focuses on these threats. However, there are two other main threats: land-use and land-cover change and overexploitation. The latter can be sub-divided into overharvesting by people and overgrazing by animals. Thor (1998) identified land-use practices such as changes in farmland

and forestry, as well as air pollution, as threats to red-listed lichens in Sweden. Habitat loss through changes in land-cover and land-use, while an obvious driver of change, often appears to be ‘taken as read’ in lichen studies though there are some notable exceptions. Grube (2010) considered the loss of foliicolous lichens was caused by logging, and Wolseley and Aguirre-Hudson (1997) found lichens that were being lost in northern Thailand due to the high rates of forest destruction. The list of threats identified by Brown *et al.* (1994) in Tasmania is the most extensive this author has encountered. It includes habitat loss, fires, plant diseases, overexploitation, invasive species and climate change.

Overexploitation

Lichens have been put to many uses by society (Nash, 2008). *Cetraria islandica* is probably the lichen that is most commonly used as a food. Dried thalli ground into flour, was used in Iceland to make bread, porridge, salads and jelly, and could be kept for years. Some Russian monasteries use lichens as substitutes for hops in brewing beer. In Japan, *Umbilicaria esculenta* used to be considered a delicacy and was sold as *iwa-take* or rock mushroom but its use has declined. In addition, lichens were used as an ingredient of curry powder and in medicines in India.

Lichens are parts of many traditional pharmacopeia, and their potential roles in modern medicine are now becoming recognised. Traditional medicine uses many lichens (Richardson (1988) cited in Nash (2008)): lichens of the genus *Usnea* are the most commonly used. *Cetraria islandica* is sold in Europe as a cure for lung diseases and catarrh, and *Peltigerra canina* is eaten in India as a remedy for liver ailments. Substances derived from lichens may exhibit antitumour activity, e.g., usnic acid has low-level activity against lung carcinoma (Shibata (1992) cited in Nash (2008)). Rundle (1978), cited in Nash (2008), stated that several of the secondary products of lichens are being used in antibacterial and antiviral compounds.

Lichens have also been used as dyes and in the making of perfumes. *Roccella montagnei* and *Parmelia omphalodes*, which were used as dyes in tanning and dyeing have now been replaced by synthetic compounds (Nash, 2008). To service the perfume industry 8,000-10,000 tonnes of *Evernia prunastri (oak moss)* and *Pseudevernia furfurracea (tree moss)* are harvested in the south of France and Morocco each year (Moxham (1980), Richardson (1988) and Hiserdt et al. (2000), cited in Nash (2008)).

Overgrazing

Lichens comprise 70-75% of the diets of caribou and reindeer. During winter they graze snow-free areas or paw at the snow cover to get to lichens underneath which can grow in carpet-like masses to heights of up to 15cm in the Arctic tundra (Nash, 2008). Lesmerises *et al.* (2011) and McMullin *et al.* (2013) illustrated their importance in the diet of forest-dwelling caribou in Canada. Changes in herd sizes and restrictions on areas that can be grazed can lead to local overgrazing; in addition, the environmental conditions that support high lichen biomass could change with shifts in climate (Lesmerises *et al.*, 2011).

Pollution

Dry and wet air pollution can depress the number of epiphytic lichens in an area. Kermit and Gauslaa (2001) found that epiphytic lichens were uncommon on *Picea abies* in some Norwegian conservation forests. They ascribed this to the toxic impacts of pollutants, particularly SO_2. Many lichens require a specific range of pH and therefore, acidification of tree canopies and trunks inhibits growth. They defined acidic bark as that which had a pH 5.2. Similar conditions have been discovered by other researchers (Legrand *et al.*, 1996) and air pollution can reduce the number of lichen phorophytes and affect bark structures (Wit, 1976). Epiphytic lichens have been ranked in terms of sensitivity to air pollution, especially $SO_{2,}$ (van Dobben & ter Braak, 1999). As well as being threatened by elevated pollution levels, epiphytic lichens are simultaneously excellent air quality indicators (Nylander, 1866; Herzig *et al.*, 1989; M.R.D. Seaward, 1993; Cislaghi & Nimis, 1997).

Lichens are extremely sensitive to other environmental stressors (or threats), as well as air pollution such as eutrophication and climate change (Nash, 1996; Galun, 1998; Nimis *et al.*, 2002). However, the potential confusion between the effects of climate change, pollution and ecosystem disturbance in deciphering the climate change impact on lichens is an obstacle. For example, research provides evidence that the combination of particulate matter and nitrogen gases significantly affect lichen growth (Purvis *et al.*, 2003). Evju and Bruteig (2013) surveyed changes in a lichen community over 15-years in Norway and showed that the effects of climate and pollution significantly affected lichens but they were unable to differentiate climate-induced changes from pollution-induced changes. Arguing along the same lines, van Herk *et al.* (2002) pointed out that lichens have been monitored in several countries to assess environmental change, but that this work has focused strongly on air pollution effects since most lichens are highly sensitive to SO_2 (Hawksworth and Rose (1970), Seaward (1993) cited in (van Herk *et al.*, 2002)). Encouragingly, the authors also noted that as air quality has improved, lichen flora have recovered.

Climate change

G. Insarov and Schroeter (2002) found that lichen communities have strong associations with climatic parameters. Lichen species distributions are also forecast to respond to climate change (Pearson & Dawson, 2003), and G. E. Insarov *et al.* (1999) noted that several epiphytic lichens in forest environments could be used to detect global climate trends. Research from western Europe has shown that while epiphytic lichens are increasing, terricolous species are decreasing as a response to global warming (Aptroot & van Herk, 2007). van Herk *et al.* (2002) has argued that as epiphytic lichens are likely to respond quickly to large-scale climate change, they are potentially an important tool for monitoring climate change.

Building on research like that above, Ellis, Coppins, and Dawson (2007) stated that the response of a species is an important tool for predicting climate change scenarios in conservation studies. They conducted research to predict the response of an epiphytic lichen – *Lecanora populicola* – to different climate change scenarios in northern Britain; in particular forecasted summer drying.

They and others have noted that future climate change is one of the greatest potential threats to lichen biodiversity (Thomas *et al.*, 2004; Thuiller *et al.*, 2005). These researchers have also indicated that there has been little research on cryptogams such as algae, mosses, liverworts or even lichens in relation to climate compared to some higher plants. Ellis, Coppins, Dawson*, et al.* (2007) surveyed a further 26 lichen species in Europe to test their response using a bioclimatic envelope approach to modelling and their results showed that there were particular threats to lichen flora in boreal montane environments. Furthermore, they state that lichen occurrence will decline further with continued climate change. G. Insarov and Insarova (1996) evaluated lichen susceptibility to climate change in Russia and found that the lichen population is very susceptible to this particular environmental stress.

Large-scale environment all changes such as global warming are likely to affect several organisms in the same way. There may be shifts in the ranges where organisms can grow in similar directions, and also a change in the density of individuals within populations. Most studies of distributional changes attributed to global warming in the northern hemisphere have examined the northward expansion of the studied organism (Thomas & Lennon, 1999; Warren *et al.*, 2001; Parmesan & Yohe, 2003; T. L. Root *et al.*, 2003; Hickling *et al.*, 2005). Recent research conducted in fungal communities in Costa Rican montane cloud forests has revealed that the community structure of fungi at the lower altitudinal ranges of these is changing as they have become warmer and drier due to the orographic cloud layer ‘lifting’ in response to global warming (Looby & Treseder, 2018). It is likely this would also affect lichen community structure in the lower elevations of cloud forests.

It appears that epiphytic lichens are likely to respond relatively quickly to broad-scale changes in the climate (Lättman *et al.*, 2009). However, Lättman *et al.* (2009) concluded that lichens can respond to global warming for only a few decades. For example, lichen species with a southern European distribution are moving northwards and invading the Netherlands in response to warming trends. A study by van Herk *et al.* (2002) showed that recent changes in the lichen flora in the Netherlands are attributable to increases in temperature. In some cases, relationships between lichen and specific climate parameters have been researched; for example, lichens that are susceptible to damage due to low temperatures (Asta *et al.*, 2008).

2.6.2 Conservation

Gilbert cited in M.R.D. Seaward (1977) noted the importance of lichen protection in Great Britain. He indicated that although there were around 1,400 species in the British Isles, habitat loss and environmental pollution are key threats to lichens, and he outlined a conservation strategy that took account of these threats. Ellis *et al.* (2014) described the future biodiversity of lichens in the United Kingdom as a major conservation challenge as many were under threat. Bolliger *et al.* (2007) noted that two of the six lichens they studied in Switzerland — *Cetrelia cetrariodes* and *Lobaria pulmonaria* – were threatened and vulnerable respectively, and outlined conservation and management strategies for these species.

In a summary of these case studies, Nascimbene *et al.* (2013) argued that it is important to conserve the threatened epiphytic lichens at all geographical scales from local to global. To aid lichen conservation planning by individual countries, they published a ‘red list’ of the lichens using the IUCN threat classes and information on each of the red-listed species.

Several authors have stated that old trees growing either alone or in a forest are good habitats for the conservation of red-listed lichens (Rose, 1991; Vanderpoorten *et al.*, 2004; Ranius *et al.*, 2008; Fritz *et al.*, 2009). Örjan *et al.* (2008) noted that the age of the trees in beech forests in Sweden was a key factor in epiphytic lichen conservation. Yet another study from Sweden promoting the conservation of macrolichen biodiversity concluded that old trees have more lichens than young trees (Uliczka & Angelstam, 1999). Therefore, allowing forests to grow to old age has been promoted as a major conservation strategy for corticolous lichens. A decade long study by Jönsson *et al.* (2016) also found that epiphytic lichens decreased as the number of old trees in the forests increased and they argued that conservation plans should be enacted using their research findings.

Thor (1998) argued that lichen conservation in Sweden should include the protection of forests, as well as controls on land-use change, restrictions on lichen collection, and the prevention of air pollution. Other strategies for conservation have been attempted. For example, Ott (1987) successfully grew *Xanthoria parietina* in natural and artificial environments as an example of a potential way to conserve lichens.

In Australia, few researchers have considered lichen conservation. Brown *et al.* (1994) studied non-vascular plants, especially lichens, in Tasmania in the context of conservation. They encountered two main difficulties: scanty information on floral composition and a lack of lichen specialists. Kantvilas (2000) published a paper on the conservation of Tasmanian lichens in which he indicated that there were around 1,000 lichen species growing on the island in a diverse range of habitats. He noted that conservation had been, and still was, a difficult issue since there is a lack of knowledge in the areas of taxonomy and identification; lichen ecology; and distribution of species. Most importantly, he argued that awareness of people about lichens and their conservation needs to be raised.

Scott *et al.* (1997) have argued for the conservation of lichens in Australia, highlighting the problems of conservation status and red-listing of species. Pharo *et al.* (2000) evaluated the use of vascular trees for bryophyte and lichen conservation in eastern Australia and found that the sites which accounted for 90% of vascular plants also contained 65% of bryophytes and 87% of lichen species. Suggesting that vascular plant conservation and epiphytic lichen conservation can operate in tandem. Lichen conservation research in South Australia is in its infancy.

2.7 Summary and knowledge gaps

Basic information on lichens is presented at the beginning of this chapter. The main types of lichen are classified by substrate (Sections 2.2 to 2.4). It is clear from the research reviewed in this chapter that new knowledge about lichens in any area is almost always created when a research investigation takes place, even in more intensively researched temperate biomes. This indicates that there are many knowledge gaps in lichenology. Those in South Australia are enormous, particularly with respect to epiphytic lichens as, to the author's knowledge, no studies on their distribution, autecology or conservation have been undertaken.

The clues for researching the autecology of colicolous lichens in South Australia therefore must be discovered in research from other parts of the world. Section 2.5 indicates that the following environmental parameters should be investigated in the context of lichen distributions:

- climatic influences, especially the roles of incident solar radiation and lichen-moisture relationships at different scales;
- tree age;
- vertical distribution of lichens in trees; and
- bark properties.

In addition, basic information on the number of lichens species and individuals needs to be reported as an addition to the types of information presented in Section 2.4. Threats to lichens are increasingly being identified, and Australia is no exception to this trend (Section 2.6); however, the conservation strategies to deal with these risks are in their infancy.

In summary, this chapter has reviewed the relevant literature, and the following chapter will outline the research design, data sources and research methods used in this thesis.

CHAPTER THREE

RESEARCH DESIGN, DATA SOURCES AND RESEARCH METHODS

3.1 Introduction

This chapter introduces this research project’s design elements, and the data sources and research methodologies used. The research methods are based on those used by other authors for sampling and analysing epiphytic lichens (e.g., May, 2000; Asta *et al.*, 2002; Brockman & Marrilees, 2002; Kondratyuk *et al.*, 2006; Costermanns, 2009; McCarthy, 2013; Nicolle, 2013; Rosabal *et al.*, 2013; Balhannah Nurseries, 2017). The chapter is structured as follows. The study area is described in Section 3.2. Section 3.3.1 describes the methods used to identify and explain the regional and mesoscale elements of the sampling scheme; while the microscale elements of the sampling scheme are described in Section 3.3.2. Lichen sampling and measurements are described in Section 3.4; lichen and tree identification procedures in Section 3.5; and bark pH measurements in the Section 3.6. Section 3.7 introduces the statistical methods used to analyse the data.

Figure 3.1 shows the activities from the beginning of the study (external inputs from the review of research literature, Chapter Two) to the analyses reported in Chapters Four, Five and Six in the form of a flow diagram.

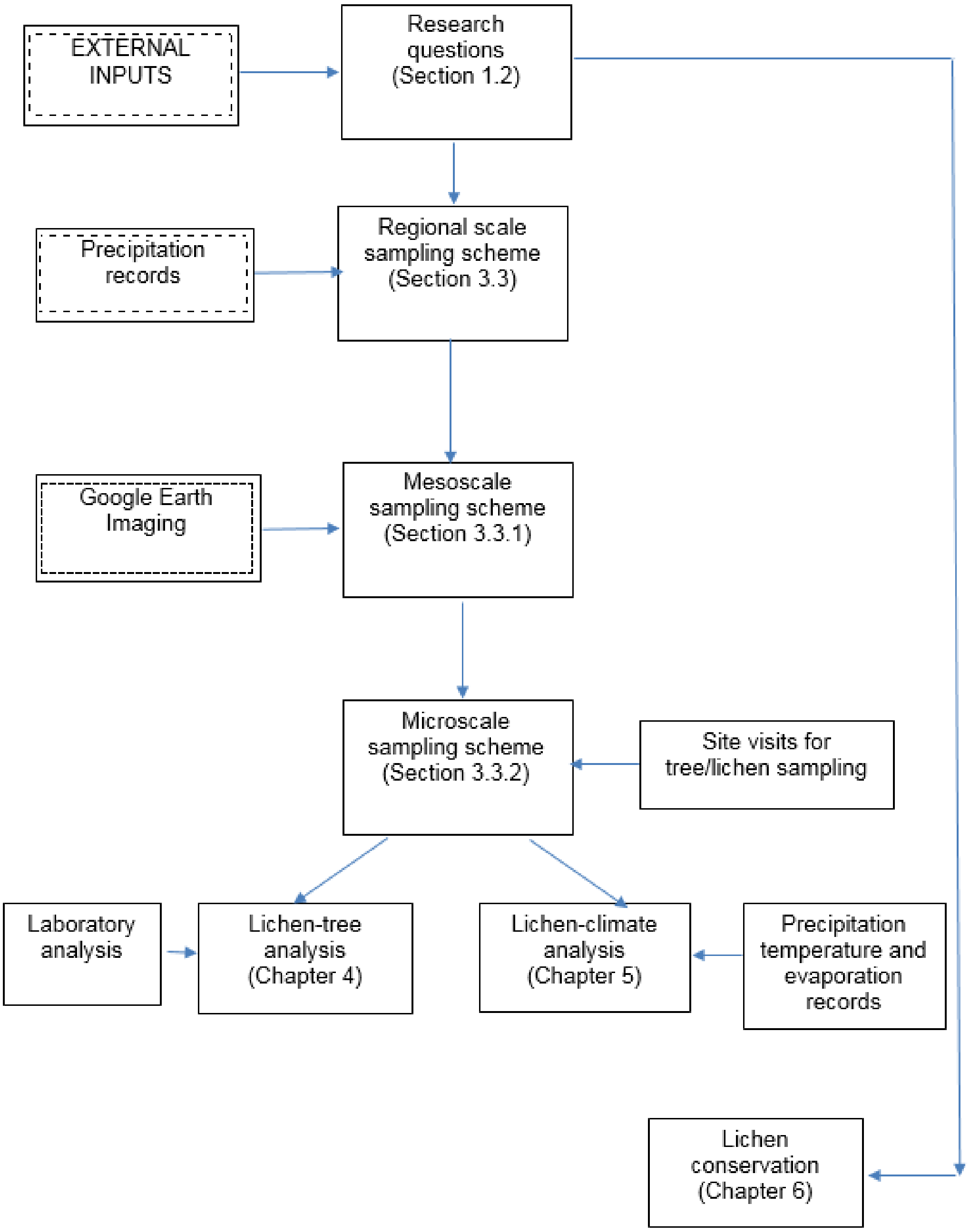


Fig. 3.1 Project design.

3.2 The study area

This research was carried out in the Adelaide Hills, Mid North and Southern Flinders Ranges regions of South Australia. These three regions are contiguous and cover approximately 22,220km^2 (Fig. 3.2) and were chosen for these following reasons:

1. The area represents distinct rainfall, temperature and evaporation gradients that it was anticipated would provide an integrated climate gradient defining an ecotone extending between warm temperate sub-humid woodlands in the south to semi-arid bushland at the desert margins to the north. It was assumed that difference in actual and potential growth of arboreal lichens could be assessed along these gradients.
2. The region contains many small towns (townships), whose origins date back to the 19th Century, in which mixed plantings of native and introduced trees have been made in reserves and along streets. This, it is argued, will facilitate an analysis of lichen growth on different tree species and between native and introduced trees; and
3. the area could be relatively easily accessed from Flinders University.

3.3 Sampling scheme

In order to evaluate the relationships between trees and epiphytic lichens (which will be discussed in Chapter Four), and climate and epiphytic lichens (Chapter Five), lichen, bark and tree (leaf, flower and fruit) measurements and samples were collected. The sampling scheme was set up to observe tree and bark properties, identify trees and obtain lichen measurements and samples.

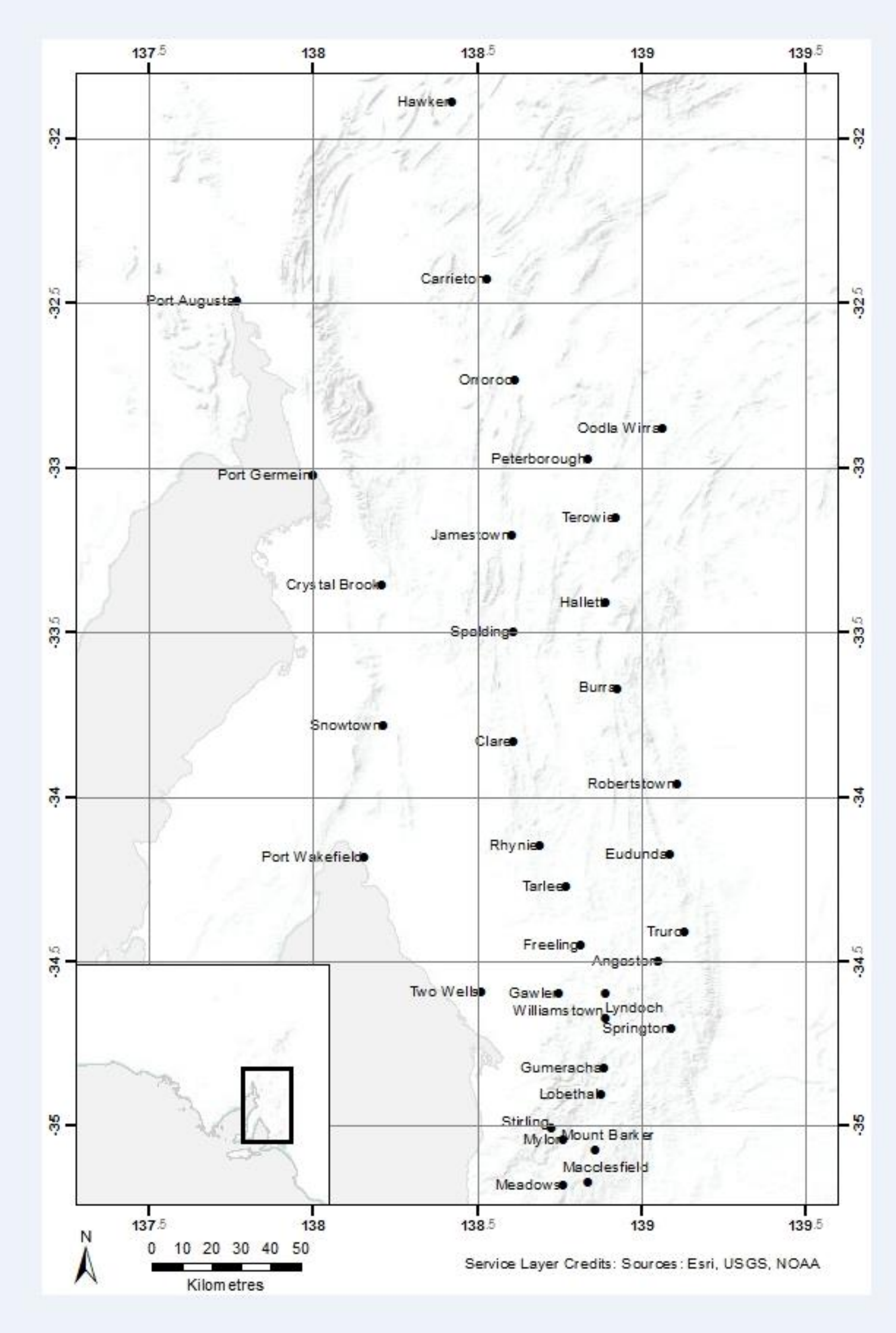


Fig. 3.2 The study sites (townships) in the Adelaide Hills, Mid North and Southern Flinders Ranges regions. Map drawn by Blythe Schembri (Flinders University)

A multiscale sampling scheme was developed which comprised:

1. 37 townships along climatically-defined transects through the region—this is termed the regional-scale sampling scheme (Figure 3.2);
2. generally, one sample site within each township—the mesoscale sampling scheme; and
3. 621 randomly selected trees at the 37 sample sites—the microscale sampling scheme.

Five main epiphytic (corticolous) lichen species were collected over the 37 sites: *Caloplaca holocarpa, Chrysothrix xanthina, Lecidella elaeochroma Physcia aipolia* and *Xanthoria parietina.* The following section outlines the regional and mesoscale elements of sampling scheme.

3.3.1 Regional and mesoscale elements of sampling scheme

The 37 townships in the Adelaide Hills, Mid North and Southern Flinders Ranges regions where lichen sampling was carried out can be seen on Figures 3.2 and 3.3. Pertinent details about the sampling sites in each township are provided in Table 3.1. Rainfall totals decrease from the Adelaide Hills northwards, with a central north-south oriented spine of higher rainfall than at stations to the east and west (Figure 3.3). Other climate gradients, e.g. seasonal precipitation totals, temperature and evaporation, are implicit in the climate gradients underpinning the sampling scheme and are discussed in Chapter Five.

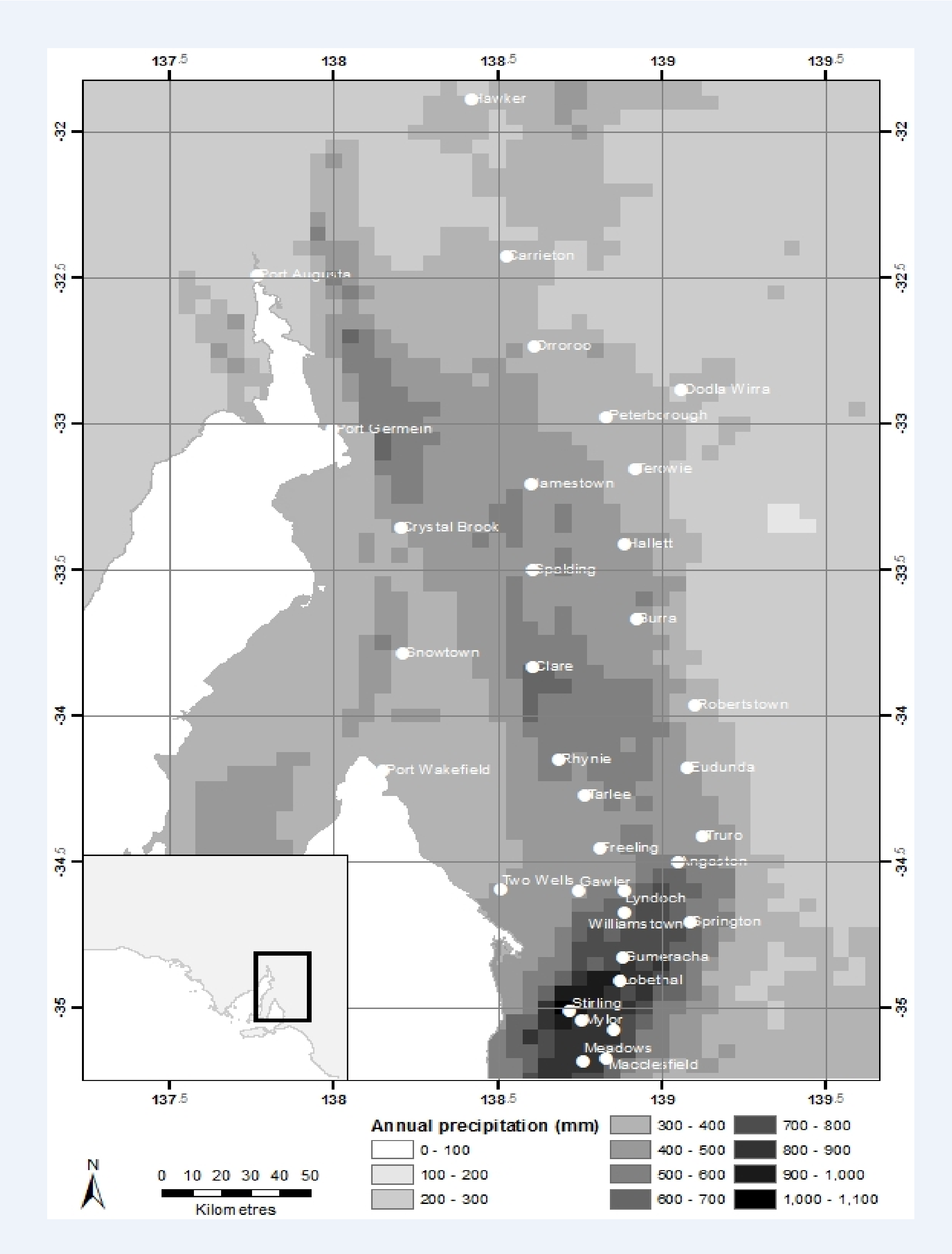


Fig. 3.2 Townships sampled overlain on mean annual precipitation data in the Adelaide Hills, Mid North and Southern Flinders Ranges. Source: Bureau of Meteorology (2016)

Climate data generated by the Queensland Government from Australian Bureau of Meteorology (BoM) data under its SILO (Scientific Information for Land Owners) program was used. These datasets cover all of Australia and are made available to land owners and researchers in Australia through the state’s Open Data Portal (Queensland Government, 2018). In these datasets BoM data from 1899 to the present day are temporally and spatially interpolated to fill gaps in records and provide better spatial coverage in areas with low densities of BoM stations (Beesley *et al.*, 2009). In this thesis 30-year means from 1985-2015 were calculated for rainfall and temperature (based on observations) and evaporation (calculated using the Penman-Monteith method) for the 37 study sites. A 30-year period was chosen as this is the WMO standard for climate means the latest that are currently available from the Bureau of Meteorology for Australia are 1961-1990 means. It was decided not to use these because they would not reflect lichen growth on young trees, nor the impacts the Millennium Drought (c. 2000-2010) in South Australia has had on lichen growth.

Mesoscale sampling was achieved by selecting sample sites for lichen measurement and collection within each township. These sites had to satisfy the following conditions:

1. they had a humid microclimate, due to the fact that they were adjacent to creeks or ponds, or were in regularly watered reserves; and
2. they had mixed tree plantings in terms of native and introduced species.

In townships where there were no suitable reserves, street trees were selected. The conditions at each site are summarised in Table 3.1.

Table 3.1 Pertinent details concerning sample sites in the Adelaide Hills, Mid North, Southern Flinders Ranges. High, medium and low rainfall classes are defined in Table 5.1.

Township, (code) and *rainfall class*	Site within township	Coordinates	Description	Conditions that lead to humid microclimate	Number of trees sampled
Angaston (ANG) *Medium*	George Angas Reserve	34^{o} 30’ 03.58” S 139^{o} 02’ 47.45” W	Reserve with mixed native and introduced trees.	A seasonal creek runs through the reserve. Reserve is irrigated.	15
Auburn (AUB) *Medium*	Reserve adjacent to Church Rd. and Wakefield River	34^{o} 01’ 35.98” S 134^{o} 41’ 12.74” W	Reserve with mixed native and introduced trees.	River Wakefield at lower end of sample site. Grassed area in reserve irrigated.	15
Bridgewater (BRI) *High*	Bridgewater Mill Reserve	35^{o} 00’ 33.58” S 138^{o} 45’ 30.67” W	Reserve with mixed native and introduced trees.	A seasonal creek runs through reserve. Reserve is irrigated.	17
Burra (BUR) *Medium*	Burra Creek Reserve	33^{o} 40’ 51.41” S 138^{o} 56’ 21.02” W	Reserve with mixed native and introduced trees.	Burra Creek runs through the reserve and is dammed to create permanent water body. Reserve is irrigated.	15
Carrieton (CAR) *Low*	Along Second St. (Trees CAR 1-10) and Pekina Creek (Trees 11-15)	32^{o} 25’ 27.12” S 138^{o} 31’ 54.89” W	CAR 1-10 (native and introduced trees) along street with light traffic. CAR 11-15 (native trees) along a seasonal creek.	Street trees, not irrigated. Trees CAR 11 to CAR 15 are along bank of a seasonal creek.	15
Clare (CLA) *High*	Pioneer Memorial Park	33^{o} 49’ 44.93” S 138^{o} 36’ 33.63” W	Reserve with mixed native and introduced trees.	Seasonal creek runs through reserve. Reserve is irrigated.	15

Crystal Brook (CRY) *Medium*	Adelaide Square	33º 21’ 04.49” S 138º 12’ 27.78” W	Town square with mixed native and introduced trees.	Irrigated	15
Eudunda (EUD) *Medium*	Centenary Gardens	34º 10’ 25.17” S 139º 05’ 02.00” W	Town reserve with mixed native and introduced trees.	Irrigated	16
Freeling (FRE) *Medium*	Freeling Oval	34º 27’ 20.10” S 138º 48’ 49.60” W	Mixed native and introduced trees, on north side of oval (FRE 1-12). Adjacent street trees are introduced species (FRE 13-20).	Parts of oval are irrigated and there is drainage across the oval in wet weather. Streets trees sampled adjacent to oval are not irrigated.	20
Gawler (GAW) *Medium*	Apex Park	34º 36’ 02.52” S 138º 44’ 49.92” W	Reserve with mixed native and introduced trees. Adjacent street trees (GAW 11-15) are introduced species.	Adjacent to Gawler River. Park is irrigated. Streets trees (GAW 11-15) adjacent to park are not irrigated.	15
Gumeracha (GUM) *High*	Federation Park	34º 49’ 21.44” S 138º 53’ 02.62” W	Reserve with mixed native and introduced trees.	Adjacent to the seasonal creek Kenton River. Park is irrigated.	23
Hallett (HAL) *Medium*	Private garden	33º 24’ 39.90” S 138º 53’ 41.30” W	Private reserve of native trees.	Seasonal creek runs through garden and floods to cover the entire area.	15
Hawker (HAW) *Low*	A.W. Burt Memorial Park	31º 53’ 12.95” S 138º 25’ 14.32” W	Mixed native and introduced trees.	Irrigated	15

Jamestown (JAM) *Medium*	Memorial Park	33^{o} 12’ 09.65” S 138^{o} 36’ 21.05” W	Mixed native and introduced trees (JAM 9-18). Street trees (JAM 1-8), also native and introduced.	Reserve is irrigated. Street trees are not irrigated.	18
Lobethal (LOB) *High*	Cudlee Creek Road	34^{o} 53’ 53.35” S 138^{o} 52’ 33.30” W	Mixed native and introduced trees in a wide central reserve along Cudlee Creek Rd., which has moderate levels of car traffic.	Not irrigated.	26
Lyndoch (LYN) *Medium*	Lyndoch Recreation Park (Trees LYN 1-10) and along the Gawler-Lyndoch Road (Trees LYN 11-15)	34^{o} 35’ 52.41” S 138^{o} 53’ 11.44” W	Mixed native and introduced trees in both cases.	Park is irrigated. Trees along road are not irrigated.	17
Macclesfield (MAC) *High*	Davenport Square Oval (Trees MAC 1-12) and Strathalbyn Rd. (Trees MAC 13-15)	35^{o} 10’ 16.41” S 138^{o} 50’ 11.96” W	MAC 1-12 mixed native and introduced trees around a sports oval (Davenport Sq.). MAC 12-15 along Strathalbyn Rd. which has moderate traffic.	Adjacent to seasonal creek. Oval is irrigated. Street trees are not irrigated.	15
Meadows (MEA) *High*	Battunga Reserve	35^{o} 10’ 54.15” S 138^{o} 45’ 24.26” W	Mixed native and introduced trees.	Irrigated	15
Mount Barker (BAR) *High*	Keith Stephenson Park	35^{o} 04’ 21.25” S 138^{o} 51’ 21.65” W	Mixed native and introduced trees.	Irrigated	19

Mylor (MYL) *High*	Mylor Oval	35º 02’ 32.92” S 138º 45’ 39.75” W	Mixed native and introduced trees.	Irrigated	24
Oodla Wirra (OOD) *Low*	Oodla Wirra Creek	32º 52’ 56.00” S 139º 03’ 45.50” W	Mixed native and introduced trees.	Seasonal creek.	15
Orroroo (ORR) *Low*	Along East Terrace, Railway Terrace and Sixth St.	32º 44’ 04.41” S 138º 37’ 01.99” W	Mixed native and introduced trees.	Well established street trees, unlikely to be irrigated. Storm water drains down to these streets as they are at the lowest part the town.	15
Peterborough (PET) *Low*	Victoria Park	32º 58’ 45.92” S 138º 50’ 02.58” W	Mixed native and introduced trees.	Irrigated and all trees are situated around an artificial lake.	15
Port Augusta (AUG) *Low*	Sid A. Welk Recreation Park	32º 28’ 18.16” S 137º 44’ 15.07” W	Reserve of mainly native trees.	Small seasonal creek runs through reserve. Not irrigated.	15
Port Germein (GER) *Low*	Along High St.	33º 01’ 12.63” S 138º 00’ 00.00” W	Mixed native and introduced trees.	Well established street trees, unlikely to be irrigated.	18
Port Wakefield (WAK) *Low*	Various streets in southern Port Wakefield	34º 11’ 09.71” S 138º 09’ 05.84” W	Mixed native and introduced trees.	Well established street trees, unlikely to be irrigated but near the coast so there is a maritime influence.	20

Rhynie (RHY) *Medium*	Unnamed reserve at junction of Horrocks Highway and Salter Springs Rd. (Trees RHY 1-8) and adjacent channel behind the Rhynie Hotel (Trees RHY 9-15)	34° 08′ 53.78″ S 138° 41′ 34.75″ W	Reserve with mixed native and introduced tree and adjacent street trees. Trees RHY 9-15 along a creek.	Well established street trees, unlikely to be irrigated. Other trees along a seasonal creek.	15
Robertstown (ROB) *Low*	Robertstown Oval	33° 59′ 34.87″ S 139° 04′ 46.30″ W	Mixed native and introduced trees, on north and west sides of the oval.	Irrigated and in a natural basin into which runoff from surrounding fields drains.	15
Snowtown (SNO) *Low*	Centenary Park Reserve along Main Street	33° 46′ 53.50″ S 138° 12′ 51.46″ W	Mixed native and introduced trees.	Well established street trees, unlikely to be irrigated.	16
Spalding (SPA) *Medium*	Along Goyder Highway and John St.	33° 30′ 08.75″ S 138° 36′ 34.10″ W	Mixed native and introduced trees.	Well established street trees, unlikely to be irrigated.	16
Springton (SPR) *High*	Springton Oval	34° 42’ 20.42” S 139° 05’ 29.32” W	Mixed native and introduced trees on north and west sides of the oval.	Oval is irrigated. Springton is located high in the Eden Valley. Cool conditions will depress evaporation rates.	20
Stirling (STI) *High*	Council Lawn	35° 00′ 21.05″ S 138° 43′ 03.14″ W	Mixed native and introduced trees.	Lawn is irrigated and is in a high rainfall, cool climate area.	20
Tarlee (TAR)	Hill Rd.	34° 16′ 42.98″ S	Mixed native and introduced trees.	New and old trees along field and road boundaries, unlikely to	16

Medium		138° 46' 03.30" W		be irrigated.	
Terowie (TER) *Low*	Terowie Arid Lands Botanic Garden	33° 09' 02.56" S 138° 55' 11.52" W	Mixed native and introduced trees.	Areas floods in wet weather.	15
Truro (TRU) *Medium*	Hero's Reserve	34° 24' 35.81" S 139° 07' 33.20" W	Reserve with mixed native and introduced trees.	Irrigated and adjacent to a seasonal creek.	15
Two Wells (TWO) *Medium*	Two Wells Bowling Club	34° 35' 42.32" S 138° 13' 55.48" W	Mixed native and introduced trees.	Irrigated	15
Williamstown (WIL) *High*	Williamstown Road (Trees WIL 1-10) and Grigg Reserve (Trees 11-15)	34° 30' 07.73" S 138° 53' 19.64" W	Reserve with mixed native and introduced trees. Adjacent street trees.	Reserve is irrigated. Street trees are not irrigated.	15

Each township was examined on Google Earth Pro© to identify all reserves, parks, sports ovals and streets with avenues of trees before they were visited and the final site selection was made (Figure 3.4). After a study site had been selected a sketch map was made of all trees; the sketch map of Pioneer Memorial Park in Clare is presented as an example (Figure 3.5). A random integer generator was used to select the trees for sampling from the entire population of trees in each reserve (Figure 3.6). At least 15 trees were selected at each study site, but wherever there was high tree species diversity up to 26 trees were selected (Table 3.1).

This number of trees is in line with the number of trees in forest and woodland stands sampled for lichens elsewhere. Larsen *et al.* (2007) investigated lichen and bryophyte distribution in relation to pollution and bark morphology in London, England and in doing so surveyed between five and nine oak trees at different locations. Lorenzini *et al.* (2003) collected lichens on 10-30 trees at various locations in Italy as part of an air pollution investigation. While these studies and other studies referenced in Chapter Two did not provide a firm figure for sample numbers, they indicate that an adequate sample size could be in the range of five to 30 trees per site. Correspondence with Professor Robert Lücking, Field Museum, Chicago about sample sizes led to his advice that 15 would be a suitable sample size, hence 15 was set as the minimum number of trees sampled at each site.

Prior to visiting the sites, permission was obtained from the relevant local government areas to sample trees and lichens in each of the townships (Appendix 3.1).

Fig. 3.3 (a, upper) and (b, lower) Images of the township of Clare. Fig. 3.3a provides an overall view, and Fig. 3.3b is zoomed in and centred on Pioneer Memorial Park — the reserve sampled in this township. Source: Google Earth Pro©

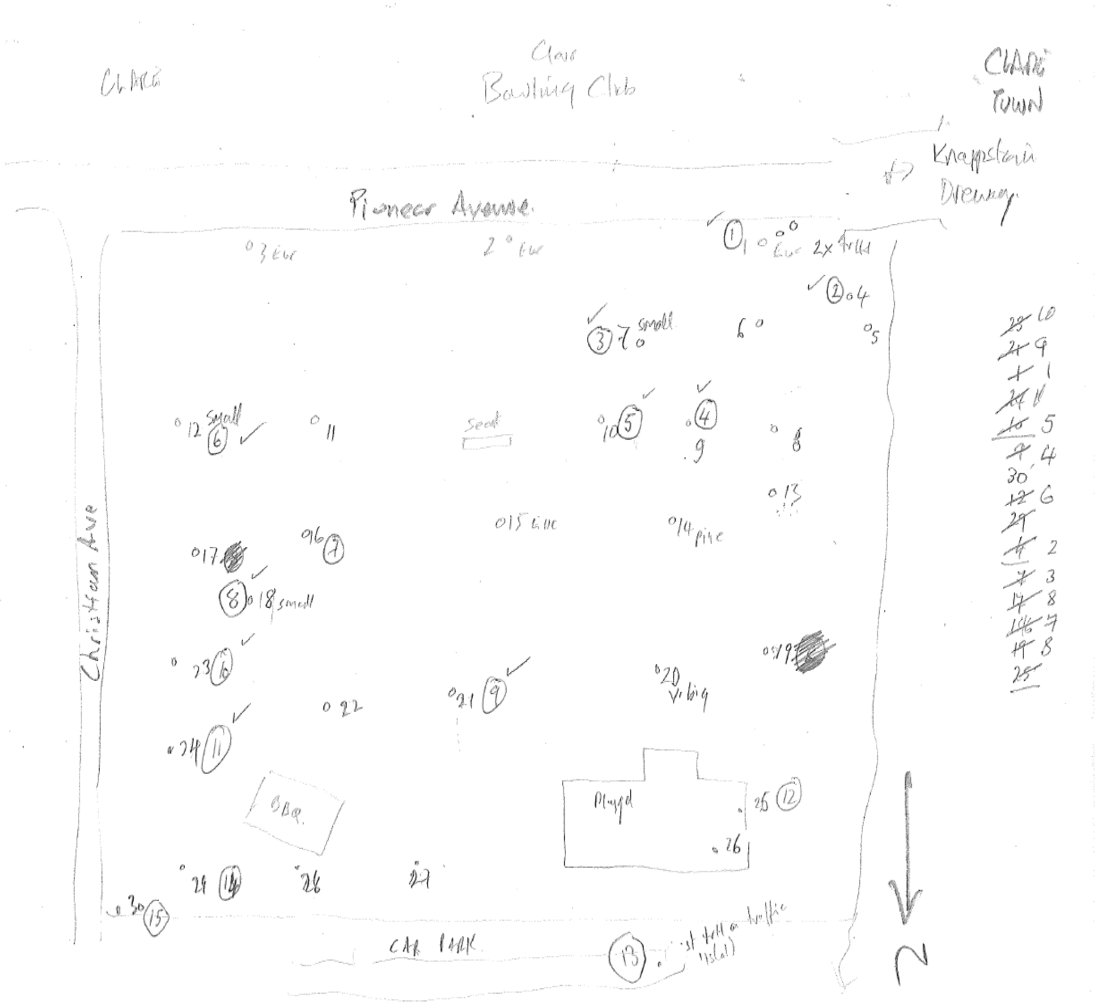
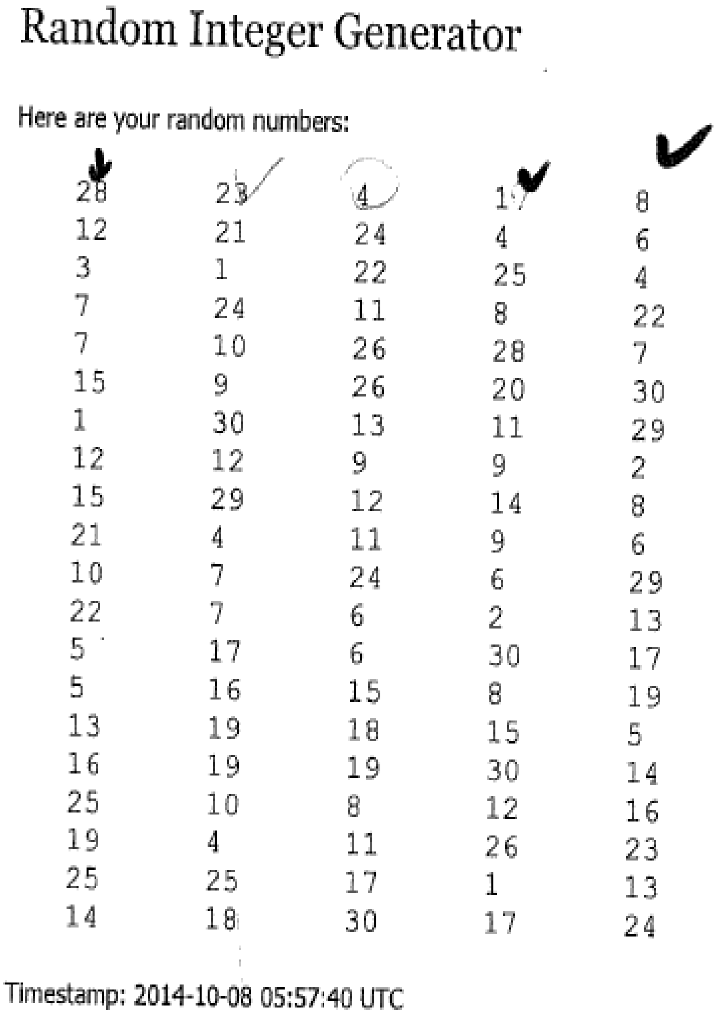


Fig. 3.4 Field sketch map for Pioneer Memorial Park, Clare. Each tree in the reserve was given a number, as per the sketch map. The circled trees are those that were selected randomly for lichen collection.



Random Integer Generator

Here are your random numbers:

```
28    23    4     17    8
12    21    24    4     6
3     1     22    25    4
7     24    11    8     22
7     10    26    28    7
15    9     26    20    30
1     30    13    11    29
12    12    9     9     2
15    29    12    14    8
21    4     11    9     6
10    7     24    6     29
22    7     6     2     13
5     17    6     30    17
5     16    15    8     19
13    19    18    15    5
16    19    19    30    14
25    10    8     12    16
19    4     11    26    23
25    25    17    1     13
14    18    30    17    24
```

Timestamp: 2014-10-08 05:57:40 UTC

Fig. 3.5 A Random Integer Generator was used to select the trees for sampling from the entire population of trees in each reserve.

3.3.2 Microscale element of the sampling scheme

The following protocol for tree and lichen measurements was used for each tree in the microscale sampling scheme:

1. the entire site and each individual tree sampled were photographed (Figures 3.7 and 3.8). An appendix of all site photographs is provided in Appendix 3.2. The individual tree photographs proved

useful if sites had to be revisited to verify observations and measurement, and in identifying tree species;

2. $d_{1.3}$ (tree diameter at 1.3m above the ground) was measured using a standard forester's DBH tape;
3. the height of the top of each tree and the bottom of the canopy (lowest major branch) were measured using a Suunto clinometer;
4. photographs of the tree trunk overlain by a vertical metal grid of five 10cm x 10cm squares (Figure 3.9) were taken with a Nikon D5300 DSLR camera. The grid was placed at aspects defined by the four-cardinal compass directions with the base of the grid being at 1.3m above the ground. For trees without lichens on their trunks at this height, only the grid at the southern aspect was photographed. However, grids in all four directions were photographed where lichens were observed anywhere on the trunk around 1.3m above the ground (Asta *et al.*, 2002);
5. the grid squares were photographed, so that they could be used to measure lichen abundance and occurrence in the laboratory. The 621 trees sampled yielded 14,420 photographs of the types explained above;
6. tree canopy branches were visually assessed to see if lichens were growing in the canopy;
7. bark type and roughness were measured on the trunk at 1.3m above the ground in the four cardinal directions. Bark types were divided into permanent and exfoliating, while bark roughness was measured by inserting tyre gauge (calibrated in millimetres) at five points and

calculating the mean depth for each of the four cardinal directions;

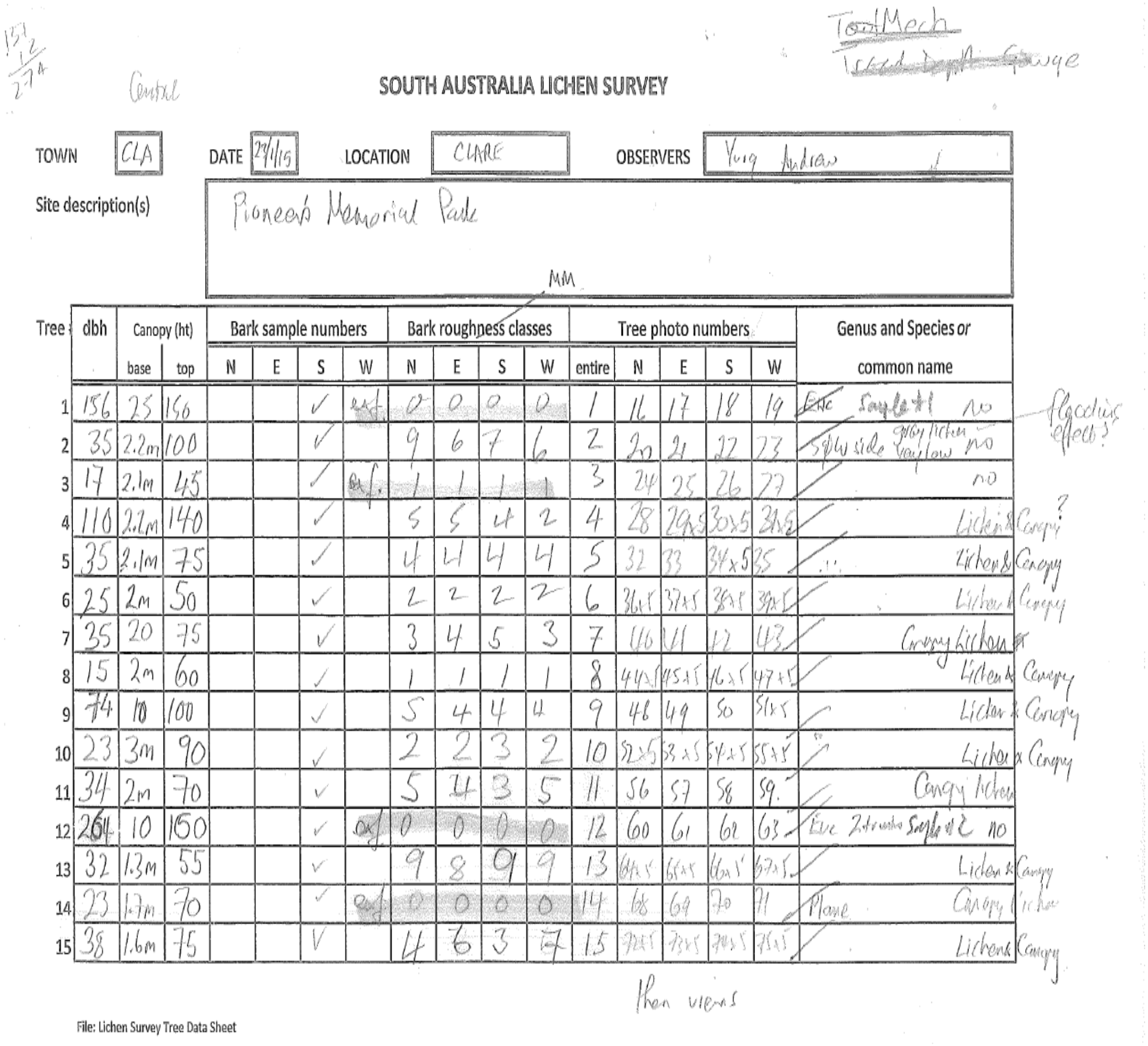
8. 10-15g bark samples were collected for chemical analyses. The amount collected was a trade-off between the amount needed for a pH test and minimising damage to trees. If available, loose bark was collected, but where it was not a mallet and chisel were used to obtain bark samples. The wounds were either left open to heal or sprayed with a proprietary bark spray — Steriprune© – depending on the instructions given by local councils when they gave permission to sample lichens. Samples were stored in paper bags in the field and taken to the Flinders University School of the Environment laboratories for analysis.

Tree and lichen measurements were recorded on survey sheets, which included the township, name of site, recorders, date, coordinates, and the following information for each tree: $d_{1.3}$, height to base of canopy, height to top of canopy, records of bark sampled and photographs taken, bark roughness measurements and tree identification information (Figure 3.10). These measurements were entered into a master spreadsheet of all trees sampled in Excel 2015.

Fig. 3.6 An example of a site photograph: Pioneer Memorial Park in Clare, 29 January, 2015.

Fig. 3.7 An example of a whole tree photograph, Tree CLA 10, in Pioneer Memorial Park in Clare, 29 January, 2015.

Fig. 3.8 The 10x10 cm metal grid used when photographing the tree trunk at 1.3m above the ground. In this example, the photograph is of the north aspect of tree CLA 6, the lichen is *Xanthoria parietina*. In addition, to the entire grid photograph, close-up photographs were also taken of each 10x10cm grid if lichens occurred in them.



151
1/2
27A

Central

~~Tool~~Mech
~~Istead Depth Ga~~uge

SOUTH AUSTRALIA LICHEN SURVEY

TOWN CLA DATE 27/1/15 LOCATION CLARE OBSERVERS Yuri Andrew

Site description(s) Pioneers Memorial Park

MM

Tree	dbh	Canopy (ht)		Bark sample numbers				Bark roughness classes				Tree photo numbers					Genus and Species *or* common name
		base	top	N	E	S	W	N	E	S	W	entire	N	E	S	W	
1	156	23	156			✓	ext	0	0	0	0	1	16	17	18	19	~~Euc~~ Sample #1 no
2	35	2.2m	100			✓		9	6	7	6	2	20	21	22	23	Sp W side grey lichen yellow no
3	17	2.1m	45			✓	ef.	1	1	1	1	3	24	25	26	27	no
4	110	2.2m	140			✓		5	5	4	2	4	28	29x5	30x5	31x5	Lichen & Canopy ?
5	35	2.1m	75			✓		4	4	4	4	5	32	33	34x5	35	Lichen & Canopy
6	25	2m	50			✓		2	2	2	2	6	36x5	37x5	38x5	39x5	Lichen & Canopy
7	35	20	75			✓		3	4	5	3	7	40	41	42	43	Canopy Lichen
8	15	2m	60			✓		1	1	1	1	8	44x5	45x5	46x5	47x5	Lichen & Canopy
9	74	10	100			✓		5	4	4	4	9	48	49	50	51x5	Lichen & Canopy
10	23	3m	90			✓		2	2	3	2	10	52x5	53x5	54x5	55x5	Lichen & Canopy
11	34	2m	70			✓		5	4	3	5	11	56	57	58	59.	Canopy lichen
12	264	10	160			✓	ef	0	0	0	0	12	60	61	62	63	Euc 2 trunks Sample #2 no
13	32	1.3m	55			✓		9	8	9	9	13	64x5	65x5	66x5	67x5	Lichen & Canopy
14	23	1.7m	70			✓	ef	0	0	0	0	14	68	69	70	71	Plane Canopy Lichen
15	38	1.6m	75			V		4	6	3	7	15	72x5	73x5	74x5	75x5	Lichen & Canopy

flocculus effect?

Then views

File: Lichen Survey Tree Data Sheet

Fig. 3.10 The field recording sheet for Pioneer Memorial Park in Clare.

3.4 Lichen and tree sampling

The method for collecting lichens was based on that used by May (2000). Entire and intact mature thalli and reproductive bodies were collected for all the lichens new to me, or where I had difficulty in identifying them, unless a species was locally uncommon. In the latter case, part of the lichen was left to regenerate. Only healthy specimens were collected, i.e., those without discoloration, as they are easier to identify. Unhealthy or infected lichens are hard to identify, and they make poor reference specimens.

One of the conditions of the collection protocol was that lichens were only collected in areas with low visibility to the public as collecting can scar the trees. Collecting lichens from trees can also open up wounds and possibly lead to diseases entering the wood. Therefore, only the outer bark was taken off the tree with the lichen specimens. The field records for the lichen specimens collected included the substrate, collection date, collector, locality, and habitat.

Samples of tree branches with leaves, flowers and/or fruits were collected from trees with either an extendable lopper or secateurs. These were stored temporarily in large plastic bags and then placed in plant presses on the day of collection.

3.5 Lichen and tree identification

The primary basis for lichen recognition and classification is their morphology. Initial identification was guided by reference books, internet resources and sample specimens. Specifically, identification of the specimens collected was initially made with reference to the *Australian Lichen Flora* (CSIRO, 1999) and the *Checklist of the lichens of Australia and its Island Territories,* (McCarthy, 2013).

Five corticolous macrolichen species were sampled in the present study: *Xanthoria parietina, Caloplaca holocarpa, Physcia aipolia, Lecidella elaeochroma, Chrysothrix xanthina.* Detailed descriptions are provided in Appendix 3.3. These identifications were confirmed by Professor Hur Jae-Seoun (Sunchon National University, South Korea) using traditional methods of preparation of microscopic slides of the thalli and apothecia (fruiting bodies) and analysis of lichen compounds by Thin Layer Chromatography (TLC). In confirming these identifications, the following references were used (Khodosovtsev *et al.*, 2004; Kondratyuk *et al.*, 2006; Kondratyuk *et al.*, 2007a, 2007b; Kondratyuk, 2008; Kondratyuk *et al.*, 2009a, 2009b; Kondratyuk *et al.*, 2010; Kondratyuk, Elix, Kärnefelt, Galanina*, et al.*, 2011; Kondratyuk, Elix, Kärnefelt, & Thell, 2011; Kondratyuk *et al.*, 2012).

Tree species were identified with the help of three scientists with expertise in South Australia’s indigenous trees (John Choate and Justin Jay, both formerly of the SA Department of Natural Resources, and Paul Green, formerly of Adelaide and Flinders University respectively), and the following key sources *Native Eucalypts of South Australia* (Nicolle, 2013) and *Native Trees and Shrubs of South-Eastern Australia* (Costermanns, 2009). Non-native trees were identified with the help of Professor Andrew Millington using the following guides and web sites: Brockman and Marrilees (2002), Eppinger (2006), Benning (2012-2017), Balhannah Nurseries (2017), Fleming (2017) and Russell (2017). Local tree nurseries were also visited to confirm some non-native tree identifications. The lichen and tree species were added to the master spreadsheet along with the relevant measurements taken in the field (Section 3.3.2) after they had been identified.

3.6 Laboratory methods

Digital photographs of the grids overlain on the trunks (Section 3.2) were converted into a database as follows:

1. Photographs of each 10 x 10cm grid were downloaded from the camera's SD card onto a laptop, and then backed up on the Flinders University server.
2. Each photograph was then displayed individually on screen.
3. Plastic film with randomly generated points was overlain on the screen and the number of points that intercepted each species of lichen in each 10 x 10cm grid cell were counted and recorded in a spreadsheet.
4. The percentage cover of each lichen was calculated as a spreadsheet function by dividing the point intercepts by the total number of points.
5. This procedure was repeated for all 14,420 grid photographs.
6. The data were exported into SPSS v.22 for statistical testing.

Kricke (2002) and Rosabal *et al.* (2013) have outlined methods for measuring bark pH. The method developed by Rosabal *et al.* (2013) was used in this research. Bark samples were dried at 105˚C for 24 hours, after which 5g of bark was ground into a powder with a mortar and pestle. The powder was then macerated in 20ml of distilled water for 24 hours and the pH of the extract measured using a 700 EUTECH pH meter. These results were also added to the master spreadsheet (Section 3.3.2).

3.7 Statistical methods

The data in the master spreadsheet were exported to SPSS version 22 for quantitative analysis. A range of statistical tests were used to examine lichen-tree and lichen-climate relationships. The tests and their results are discussed in Chapters Four and Five. Initial testing of the data showed that almost all parameters have non-parametric distributions.

In Chapter 4, Yates X^2 analysis for continuity was used to test hypotheses related to lichens on native and non-native trees, and to test the relationship between bark shedding and lichen cover. In the same chapter, Pearson's correlation coefficients were calculated to examine associations between lichen cover and bark pH and roughness. In Chapter Five, Kruskal-Wallis H was used to test the microclimatic differences between four aspects (north, east, south and west) of the trunk in three classes of rainfall sites; and Dunn's *post hoc* test was used to examine the differences in aspect in more detail. Also, in this chapter, the Wilcoxon signed-rank test was used to test differences in the occurrence of trunk and canopy lichens and Pearson's correlation coefficients were calculated to examine associations between them. Kendall's Tau (τ) was used to test associations between the climate parameters and lichen cover and frequency, as well as distance from the sea. All tests were carried out in SPSS version 22.

3.8 Summary

This chapter has described the main elements of the design of this project, sampling, collection and analytical methods. Chapters Four and Five will present the analyses of the relationships between epiphytic lichens and tree properties, and epiphytic lichens and climate respectively.

CHAPTER FOUR

TREE-EPIPHYTIC LICHEN RELATIONSHIPS IN SOUTH AUSTRALIA

4.1 Introduction

This chapter builds on the research synthesised in Chapter Two, specifically Sections 2.4.2 on corticolous lichens, Section 2.5.3 on lichen and tree diameter, height and age relationships, and Section 2.5.4 on bark properties and lichens. It starts by outlining some basic information relating to the lichens collected (Section 4.2) and a short discussion of species richness (Section 4.3), before moving onto the relationships between corticolous lichens and tree species (Section 4.4), tree height and diameter (Section 4.5), and bark properties (Section 4.6).

4.2 Lichens in the study area

Five corticolous macrolichens were found in the approximately 22,220 km^2 study area. In decreasing frequency of their occurrence on all 621 trees sampled, they were:

- *Xanthoria parietina* (L.) Th. Fr., the Common Wall Lichen (Figure 4.1)
- representatives of the *Caloplaca holocarpa* group (Arup, 2009), (Figure 4.2);
- *Physica aipolia* (Ehrh. Ex. Humb.) Fürnr., the Hoary Rosette Lichen (Figure 4.3);
- *Lecidella elaeochroma* (Ach.) M.Choisy, which does not have a common name, (Figure 4.4); and
- *Chrysothrix xanthina* (Vain.) Kalb., the Gold Dust Lichen (Figure 4.5).

Further details are provided in Appendix 4.1.

Fig. 4.1 Xanthoria parietina on Acacia pendula at Truro.

Fig. 4.2 Caloplaca holocarpa on Acer negundo at Clare.

Fig. 4.3 Physica aipolia on Celtis australis at Freeling.

Fig. 4.4 Lecidella elaeochroma on Cupressus spp. at Mylor.

Fig. 4.5 Chrysothrix xanthina on Grevillea robusta at Jamestown.

Only corticolous lichens were found on the trees sampled, no foliicolous lichens were observed. In Chapter Two I anticipated that the number of epiphytic lichen species in the study area would be low because much of it has either an arid or semi-arid climate. The number of species observed in the area, five in approximately 22,220km^2 (0.22 per 1000km^2) is comparable to that of Bolliger *et al.* (2007) who found six epiphytic lichens across a 41,000km^2 study area (0.15 per 1000km^2) in Switzerland. Hur, Harada, Oh*, et al.* (2004) found 600 individual lichens at 14 sites in South Korea, compared with the 254 trees with lichens (out of 621 trees sampled) at 37 sites in this study.

4.3 Lichen species richness

Species richness varies from zero to three lichens per tree (Figure 4.6). Only six trees had three lichens growing on them, one individual each of *Eucalyptus torquata*, *Grevillea robusta, Melaleuca lanceolata* and *Melia azedarach* and two *Celtis australis* (Table 4.1).

Fig. 4.6 Frequency of trees by species richness class.

There is no clear pattern to the trees with three lichens in terms of species or location. However, when the 32 trees with two and three lichens are examined two things stand out. First, the relatively high numbers of *Celtis australis* and *Melia azedarach* in the list. In fact, all the *Celtis australis* sampled had either two or three lichens; though these were also all sampled at one site, Freeling, and had been planted at the same time. Four of the 13 *M. azedarach* sampled had two or three lichens. They occurred at two sites, Freeling and Jamestown. All the *M. azedarach* trees at Jamestown were planted at the same time.

Table 4.1 Trees with two or three lichens.

Tree #	*Tree species*	Xp	Ch	Pa	Le	Cx
Tru06	*Acacia pendula*	*	*			
Cla15	*Acer negundo*	*	*			
Gum21	*Betula pendula*	*	*			
Eud11	*Brachychiton populneus*	*	*			
Jam02	*Callistemon sp.*	*	*			
Two15	*Callistemon sp.*	*			*	
Ger07	*Casuarina glauca*			*	*	
Fre05	*Celtis australis*	*		*		
Fre04	*Celtis australis*	*	*	*		
Fre06	*Celtis australis*	*		*	*	
Myl08	*Cupressus sp.*	*			*	
Spa13	*Eucalyptus ochrophlola*	*			*	
Hal12	*Eucalyptus sp.*	*	*			
Hal08	*Eucalyptus torquata*	*	*	*		
Spa10	*Fraxinus excelsior*	*	*			
Jam10	*Grevillea robusta*	*	*			*
Bur14	*Jacaranda mimosifolia*	*	*			
Fre19	*Jacaranda mimosifolia*	*		*		
Ger09	*Lagunaria patersonia*		*		*	
Mea06	*Liquidamber styraciflua*	*	*			
Orr05	*Melaleuca lanceolata*	*	*		*	
Jam11	*Melia azedarach*	*		*		
Jam13	*Melia azedarach*	*				*
Fre08	*Melia azedarach*	*		*		
Jam15	*Melia azedarach*	*	*			*
Sno01	*Pinus halepensis*	*	*			
Hal14	*Pittosporum phllyreoides*	*	*			
Cla10	*Quercus palustris*	*	*			
Myl17	*Quercus rober*	*	*			
Lob08	*Salix contorta*	*	*			
Rhy11	*Ulmus procera*	*	*			

Xp = *Xanthoria parietina*, Ch = *Caloplaca holocarpa* group, Pa = *Physica aipolia*, Le = *Lecidella elaeochroma*, Cx = *Chrysothrix xanthina*

4.4 Tree species-lichen relationships

The trees sampled at the 37 study sites are listed in Table 4.2, and were grouped on the basis of their geographical ranges:

1. Trees whose native geographical range is in the Adelaide Hills, the Mid North and the southern Flinders Ranges are listed in Column One in Table 4.2.

2. Trees with native geographical ranges elsewhere on the Australian mainland are listed in the second column. These are main trees from the western Australian biodiversity hotspot (Mittermeier et al 2000) or the east coast that have been planted as ornamental native trees in amenity plantings.
3. Trees whose original geographical range is external to the Australian mainland are listed in the third column. These trees originate mainly in cool and warm temperate climate zones in Eurasia, and North and South America. Though this group also includes two commonly planted trees from Australian-administered Pacific Islands, the Norfolk Island Pine (*Araucaria heterophylla*) and the Norfolk Island Hibiscus (*Lagunaria patersonia*). Both are endemic to Norfolk Island, and the latter to Lord Howe Island as well.

Therefore, all of the trees in the second and third groups (columns) are non-native introductions to the region that was studied. They have mainly been deliberately planted in reserves or along streets or are amenity or garden escapees that have naturalised. There is a slight possibility that some of the second group may be Australian natives that have extended their ranges, though there is no biogeographical evidence to confirm this.

The species listed in Table 4.2 were also divided into three rows. The first row consists of species that had no lichens on any of the individuals sampled. The second row contains species that had lichens on some individuals but not all trees. The percentage of trees with lichens is provided for each tree species or genus. The third row contains species that always had lichens. Therefore, Table 4.2 has nine cells:

1. Trees native to the Adelaide Hills, the Mid North and/or Southern Flinders Ranges with no lichens.
2. Trees native to the Adelaide Hills, the Mid North and/or Southern Flinders Ranges, of which some individuals had lichens.
3. Trees native to the Adelaide Hills, the Mid North and/or Southern Flinders Ranges that always had lichens.
4. Trees whose native geographical ranges are elsewhere on the Australian mainland with no lichens.
5. Trees whose native geographical ranges are elsewhere on the Australian mainland, of which some individuals had lichens.
6. Trees whose native geographical ranges are elsewhere on the Australian mainland that always had lichens.
7. Trees external to the Australian mainland with no lichens.
8. Trees external to the Australian mainland, of which some individuals had lichens.
9. Trees external to the Australian mainland that always had lichens.

Table 4.2 Trees species or genera sampled in the study area. Authoritative references for these species are provided in Appendix 4.2. Number of individuals, n, indicated thus [n]; and the percentage of individuals with lichen in the second row of the table are provided after each species/genus.

Frequency of lichens growing on trees sampled	Native to the Adelaide Hills, Mid North and/or Southern Flinders Ranges	Native to other parts of the Australian mainland	Not native to the Australian mainland
TREES WITHOUT TRUNK LICHENS	*Acacia iteaphylla [1]* *Eucalyptus dumosa [1]* *Eucalyptus gracilis [1]* *Eucalyptus intertexta [1]* *Eucalyptus porosa [18]* *Eucalyptus socialis [4]* *Indigofera australis [1]* *Melaleuca halmaturorum [2]*	*Acacia stenophylla [1]* *Acacia sp. [2]* *Agonis flexuosa [1]* *Callitris preisseii [6]* *Casuarina cristata [2]* *Corymbia citriadora [1]* *Corymbia ficifolia [1]* *Eucalyptus behriana [1]* *Eucalyptus erythrocorys [1]* *Eucalyptus foecunda [1]* *Eucalyptus forrestiana [2]* *Eucalyptus gunnii [1]* *Eucalyptus oleosa [1]* *Eucalyptus platypus subsp. heterophylla {2]* *Eucalyptus platypus subsp. platypus [1]* *Eucalyptus preissiana [1]* *Eucalyptus spathulata [2]* *Eucalyptus tetrapleura [2]*	*Abies* sp. *[1]* *Acer japonicum* cultivar *[2]* *Araucaria heterophylla [1]* *Cupressus sempervivens [1]* *Pyrus communis [1]* *Rhamnus alaternus [2]* *Salix matsudana [1]* *Salix fragilis [2]* *Schinus molle [14]*

		Eucalyptus utilis [3] *Eucalyptus woodwardii [4]* *Grevillea acanthifolia [3]* *Melaleuca gibbosa [1]* *Melaleuca uncinata [1]*	
TREES ON WHICH TRUNK LICHENS SOMETIMES WERE FOUND GROWING. Percent values refers to the proportion of individuals with trunk lichens.	*Allocasuarina muelleriana [3] 33%*	*Acacia salicina [2] 50%*	*Acer negundo [4] 75.0%*
	Callitris columellaris [5] 20%	*Brachychiton populneus [7] 71.4%*	*Acer palmatum* cultivars *[3] 66.7%*
	Callistemon viminalis “Harkness” [13] 38.5%	*Callistemon sp. [20] 43.8%*	*Betula pendula [6] 50%*
	Eucalyptus camaldulensis [30] 20%	*Casuarina glauca [8] 37.5%*	*Conifers (unidentified) 66.7*
	Eucalyptus cladocalyx [4] 50%	*Casuarina sp. [4] 50%*	*Cupressus* sp.*80.0*
	Eucalyptus gillii [4] 25%	*Eucalyptus calycogona [4] 25%*	*Eucalyptus emerophylla [3] 33.3%*
	Eucalyptus leucoxylon [15] 26.7%	*Eucalyptus piperita [3] 33.3%*	*Fagus* sp. *33.3%*
	Melaleuca lanceolata [4] 66.7%	*Eucalyptus torquata [40] 28.6%*	*Fraxinus angustifolia [21] 89.9%*
	Melaleuca sp. *[5] 25.0%*	*Eucalyptus sp. [41] 7.2%*	*Fraxinus excelsior [34] 73%*
		Grevillea robusta [2] 50%	*Fraxinus* sp. *[24] 91.7%*
			Jacaranda mimosifolia [19] 60.0%
			Koelreuteria paniculata [4] 75.6%
			Lagunaria patersonia [9] 11.1%
			Larix sp. *[2] 50%*
			Liquidambar styraciflua [12] 66.7%

			Malus pumila [3] 33.3% *Melia azedarach [13] 84.6%* *Pinus halepensis [35] 31.4%* *Platanus orientalis [4] 11.1%* *Populus deltoidies [3] 33.3* *Populus nigra italia [9] 11.1%* *Prunus* sp. hybrid *[5] 40.0%* *Quercus palustris [8] 87.5%* *Quercus rober [14] 50.0%* *Salix matsudana contorta [6] 66.7%* *Ulmus procera [16] 43.0%*
TREES ON WHICH TRUNK LICHENS WERE ALWAYS RECORDED	*Callitris gracilis [1]* *Eremophila longifolia [1]* *Eucalyptus microcarpa [3]* *Pittosporum angustifolium [2]*	*Acacia pendula [2]* *Acacia salina saligna* complex *[1]*	*Coprosma repens [1]* *Celtis australis [3]* *Pinus radiata [2]* *Tilia* sp. *[2]*

Not all trees were identified to species level. Importantly, two genera with high numbers of trees that were not always identified to species level were *Eucalyptus* and *Callistemon*, with 42 and 20 individuals respectively. All of the Eucalypts that were not identified to species level were from individuals where only leaves were sampled. The strong preference is always to sample flowers or gum nuts of Eucalypts, but these were not found on all trees of this genus when they were sampled in the field. In some cases, sites were visited more than once in case trees were in flower; and in a few cases, distinctive leaves and/or bark or tree form seen in the field photographs were an aid to identification to species level. Nonetheless, the 42 individuals listed in Table 4.2 as *Eucalyptus* sp. are leaf only samples that cannot be identified to species unambiguously. The case of the 20 individuals of *Callistemon* that were not identified to species level is slightly different. The *Callistemon viminalis* cultivar *"Harkness"* which is also known as the "Gawler Hybrid" (Dr. Paul Green, Flinders University, personal communication) is a widely planted small tree in gardens, along streets and in reserves throughout the study area, as the geographical origin of the cultivar's name suggests. This variety of bottlebrush is commonly described on most Australian gardening websites. Some *Callistemon* that were collected were not in flower and could not be unambiguously identified. Given the frequency of its planting, it is probable that many of these 20 individuals are also the "*Harkness*" cultivar, but they were left conservatively at the genus level. All the trees identified as *Eucalyptus* sp. and *Callistemon* sp. were placed in the second group of trees, trees whose native geographical ranges are elsewhere on the Australian mainland; though some individuals could be from species native to the study area.

The ‘trees native to the Adelaide Hills, the Mid North and Southern Flinders Ranges with no lichens’ cell in Table 4.2 contains ten species. These were mainly species of *Acacia* and *Eucalyptus*. Seven of the species were only represented by one individual. The cell was dominated by 22 trees of *Eucalyptus porosa* and *E. socialis.* All of the species are native to the driest parts of the Mid North and the southern Flinders Ranges, with exception of *Melaleuca halmaturorum* which prefers sandy coastal sites.

The cell containing ‘trees native to the Adelaide Hills, the Mid North and Southern Flinders Ranges that sometimes had lichens’ contained eight species and trees identified to genus level. In increasing order of lichen occurrence these were *Eucalyptus camaldulenis, Callitris columellaris*, *E. gillii, Melaleuca* sp. and *E. leucoxylon*, all of which had between 20% and 26.7% of individuals with lichens. These were followed by *Allocasuarina muelleriana* (33.3%) and *Callistemon viminalis “Harkness”* (38.5%). The highest percentages of lichens were found on *Eucalyptus cladocalyx* and *Melaleuca lanceolata* with 50% and 66.7% respectively. However, only four individuals each were recorded for the latter two species. Low numbers of individuals sampled for some species of trees creates issues when examining percentages of lichens occurring on trees in Table 4.2. Therefore, this description and discussion proceeds with that caveat. However, two of the most commonly occurring trees in the Mid-North and Adelaide Hills, particularly, also occurred in this cell. *Eucalyptus camaldulenis*, the Red River Gum, which is common along watercourses throughout the state. Five of the 20 individuals sampled had lichens on their trunks. This low proportion of lichen occurrence is due to the fact that *E. camaldulenis* sheds its bark prolifically and, as will be seen in Section 4.6.3, that process greatly reduces the probability of finding lichens on trees of this species. Lichens were also found frequently on *E. leucoxylon*. Undoubtedly some of these were specimens of *E. leucoxylon* var. *leucoxylon*, the South Australian Blue Gum (Nicolle, 2013); but others are probably specimens of the widely planted ornamental *E. leucoxylon* ''*Rosea*'' (Brookings and Kleinig, 2001). Generally, it is easier to be more certain of percentages of lichens on these two species than on most of the species in the first group of trees that are native to the study area. The caveat about low numbers of individuals argument also applies to the four species that 'always had lichens' in this group of trees, which comprised only seven individuals in total.

The second group of trees, i.e., those native to the Australian mainland but not the study area, were also grouped according to lichen occurrence. The group of trees without lichens comprised 40 individuals across 23 species. It was dominated by 13 species of *Eucalyptus* and two closely related *Corymbia.* The species with the most individuals were *Callitris preisseii* (6) and *Eucalyptus woodwardii* (4). Ten of the Eucalypts and one *Corymbia* are endemic to south west Western Australia; *Corymbia ficifolia, Eucalyptus erythrocorys*, *E. foecunda*, *E. forrestiana*, *E. platypus* subsp. *heterophylla*, *E. platypus* subsp. *platypus*, *E. preissiana*, *E. utilis*, *E. spathulata*, and *E. woodwardii.* One is native to New South Wales (*E. tetrapleura*) and another to Tasmania (*E. gunnii*). *E. behriana* is native to south eastern Australia, and its range includes south east South Australia. The South Australian flora shows records for the

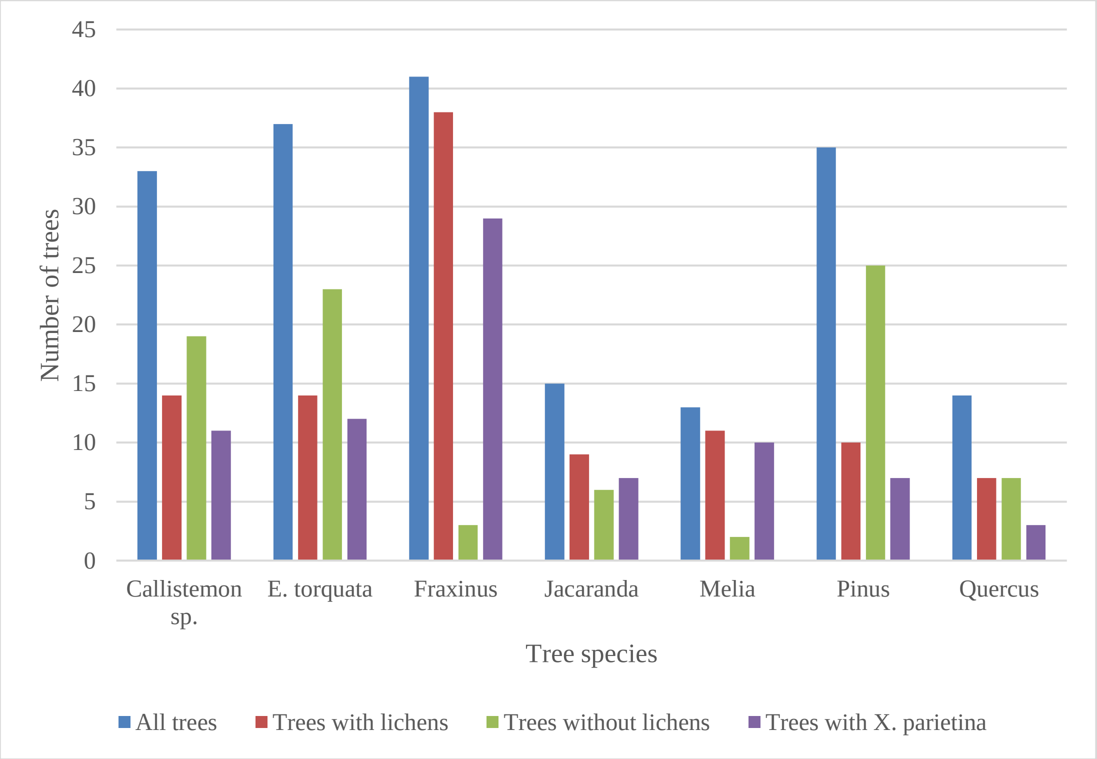
Eyre Peninsula (Electronic Flora of South Australia, n.d.); however, as its native range does not include the study area it was included in this group of trees, rather than native trees. The original geographical ranges of the other species in this cell are either arid inland eastern Australia (*Acacia stenophylla*, *Callitris preisseii*), north eastern Australia (*Corymbia citriodora*), along the southern Australian coast (*Melaleuca gibbosa*) or Western Australia (*Agonis flexuosa*, *Callitris presseii*). *Melaleuca uncinata* has a disjunct distribution that includes parts of south west Western Australia, the Eyre Peninsula and coastal regions of New South Wales and Victoria.

E. torquata and other species of *Eucalyptus* dominate the trees from elsewhere in Australia with variable lichen cover. Just over a quarter of the 35 specimens of *E. torquata* had trunk lichens, this tree is widely planted in the study area though it is native to Western Australia. The percentage of trunk lichens on the 42 Eucalypts that were not identified to species level was 7.2%. One of the three specimens of *E. piperita* had trunk lichens. The other trees had relatively high numbers of trees with lichens, perhaps the most significant of these was *Brachychiton populneus*, Kurrajong, which had trunk lichens on six of the seven trees sampled and *Casuarina glauca* (trunk lichens on 50% of eight trees sampled). Nine of the 20 *Callistemon* not identified to species had lichens (43.7%), which is similar to the percentage on *Callistemon viminalis "Harkness"* and probably supports the idea that these individuals are in fact *Callistemon viminalis "Harkness"* as hypothesised earlier. Only two trees from elsewhere in Australia always had trunk lichens — *Acacia pendula and A. salina saligna* complex.

Nine tree species (28 individuals) that are not native to the Australian mainland did not have lichens. These originate from various biogeographical regions around the world and in each case only had one or two individuals per species. The exception is the widely planted American Peppertree, *Schinus molle*, which is native to arid and semi-arid South America. None of the 14 individuals sampled had lichens growing on them.

A long list of non-natives had macrolichen growth on their trunks. If the 13 species with at least six individuals are considered, the highest proportion of trunks with lichens (89.5%) was encountered on the various cultivars of the Narrow-leaved Ash — *Fraxinus angustifolia*. The other ash species that is frequently planted in the study area, the European Ash (*F. excelsior*) also has a very high percentage of trunk lichens (73%). Trunk lichens are found frequently on Pin Oak (*Q. palustris*, 87.5%) and the Umbrella Tree (*Melia azedarach*, 84.6%). Approximately two-thirds of specimens of the South American native — *Jacaranda mimosifolia*; the North and Central American native, the Sweet Gum — *Liquidamber styraciflua;* and the Hankow Willow variety of *Salix matsudana*, had slightly lower proportions of lichens. Lower proportions of trees with trunk lichens were found on the sampled specimens of Aleppo Pine (*P. halepensis*), English Oak (*Q. robur*), English Elm (*U. procera*) and Silver Birch (*Betula pendula*). The proportions of individuals of Lombardy Poplar (*P. nigra italica*) and the Norfolk Island Hibiscus (*Lagunaria patersonia*) with lichen cover were very low.

Figure 4.7 shows how lichens are distributed in seven ‘trees groups’ that represent the most frequently occurring genera and species in the study area: combined *Callistemon viminalis* “*Harkness*” and *Callistemon* sp. (see arguments for combining these above); *Eucalyptus torquata*, combined *Fraxinus angustifolia* and *F. excelsior*, *Jacaranda mimosifolia*, *Melia azedarach*, *Pinus halepensis*, and *Quercus robur*.



Callistemon – combined *Callistemon viminalis* “*Harkness*” and *Callistemon* sp.; E. torquata = *Eucalyptus. torquata*; Fraxinus = combined *Fraxinus angustifolia* and *F. excelsior*); Jacaranda = *Jacaranda mimosifolia*; Melia = *Melia azedarach*; Pinus = *Pinus halepensis*; Quercus = *Quercus robur*.

Fig. 4.7 Lichen occurrence in the most frequently occurring ‘tree groups’.

The ratios between the four tree-lichen groups in Figure 4.7 for the Callistemon, *E. torquata* and Pinus ‘tree groups’ are similar, with more individuals without lichens than with lichens. The Fraxinus and Melia ‘tree groups’ showed the opposite distribution with a much higher ratio of trees with lichens to all trees, and trees with *X. parietina* to all trees, than the other three classes. The Jacaranda and Quercus ‘tree groups’ exhibit a lichen distribution that is intermediate between the other five ‘tree groups’. Two findings can be drawn from this figure. First, for some genera and species the ratios of trees with and without trunk lichens on their trunks shows distinct variations. However, with so many species in this research project represented by very few individuals (*cf.* Table 4.2) this finding has a relatively low base numerical base and requires extensive research to substantiate it more broadly. Second, if the Callistemon, *E. torquata* and Pinus ‘tree groups’ are considered, there is no significant difference between the two ‘tree groups’ containing native species — Callistemon and *E. torquata* – and the introduced Jacaranda.

To test whether lichens occurred preferentially on (i) trees native to the study area, (ii) native to elsewhere in Australia but not in the study area, or (iii) trees introduced from other biogeographical regions a series of 2x2 contingency table were analysed (Tables 4.3 and 4.4) (Ennos, 2000). For each of the contingency tables, a null hypothesis that there was no significant difference in lichen occurrence between the groups of trees was tested. Yates χ^2 analysis which corrects for continuity was used. In addition to the χ^2 values, their probabilities were calculated. Phi coefficients (Φ), which are equivalent to Pearson correlation coefficients, were calculated (Davenport & Al-Sunhurry, 1991). These range from no (0) to high association (+1 and -1). Probabilities for one- and two-tailed Fisher’s Exact tests were also calculated. The results are summarised in Table 4.3.

Table 4.3 Corticolous trunk lichens and trees: 2x2 contingency tables. Trees native and not native to the study area by individual trees (a), species (b) and species and genera (c). Trees native and not native to the Australian mainland by individual trees (d), species (e) and species and genera (f).

(a)

		Trees native to study area	Trees not native to study area	Sums
No lichens present	Observed	29	61	12
	Expected	*19.42*	*70.58*	
Lichens present	Observed	105	426	531
	Expected	*114.58*	*416.42*	
Sums	Observed	134	487	621
	Expected			

(b)

		Trees native to study area	Trees not native to study area	Sums
No lichens present	Observed	10	33	43
	Expected	*10.41*	*32.59*	
Lichens present	Observed	13	39	52
	Expected	*12.59*	*39.41*	
Sums	Observed	23	72	95
	Expected			

(c)

		Trees native to study area	Trees not native to study area	Sums
No lichens present	Observed	13	50	63
	Expected	*14.24*	*48.76*	
Lichens present	Observed	13	39	52
	Expected	*11.76*	*40.24*	
Sums	Observed	26	89	115
	Expected			

(d)

		Trees native to the Australian mainland	Trees not native to the Australian mainland	Sums
No lichens present	Observed	65	25	90
	Expected	*48.26*	*41.74*	
Lichens present	Observed	268	263	531
	Expected	*284.74*	*246.26*	
Sums	Observed	333	288	621
	Expected			

(e)

		Trees native to the Australian mainland	Trees not native to the Australian mainland	Sums
No lichens present	Observed	33	10	43
	Expected	*26.25*	*16.75*	
Lichens present	Observed	25	27	52
	Expected	*31.75*	*20.25*	
Sums	Observed	58	37	
	Expected			

(f)

		Trees native to the Australian mainland	Trees not native to the Australian mainland	Sums
No lichens present	Observed	36	19	55
	Expected	*31.36*	*23.64*	
Lichens present	Observed	25	29	54
	Expected	*29.64*	*22.36*	
Sums	Observed	61	48	
	Expected			

Table 4.4 Summary statistics for contingency table analyses.

	Individual trees		**Species**		**Species and Genera**	
	Native to study area/ non native[1] (4.3a)[3]	**Native to Australian mainland/ non-native[2] (4.3d)**	**Native to study area/non-native (4.3b)**	**Native to Australia mainland/ non-native (4.3e)**	**Native to study area/non-native (4.3c)**	**Native to Australia mainland/ non-native (4.3f)**
Φ	-0.11	-0.15	+0.02	-0.29	+0.05	-0.22
Yates χ^2	6.33	13.78	0.0	6.97	0.11	4.75
χ^2 *p*	0.012	0.000**	1.000	0.008**	0.740	0.029
Fisher's exact test						
1-tailed *p*	0.007*	0.000**	0.519	0.004**	0.368	0.015
2-tailed *p*	0.009*	0.000**	1.000	0.006**	0.656	0.022

[1] These tests are between (i) trees native to the study area (col. 1, Table 4.2), and (ii) trees native to elsewhere in Australia and those whose origins are not on the Australian mainland (cols. 2 and 3, Table 4.2).
[2] These tests are between (i) trees native to the study area and elsewhere on the Australian mainland (cols. 1 and 3, Table 4.2), and (ii) those whose origins are not on the Australian mainland (cols. 3, Table 4.2).
[3] The numbers in parentheses refer to table number in Table 4.3.
** = significant at 99%, * = significant at 95%

In two contingency tables (Tables 4.3d and 4.3e) the null hypotheses were rejected, indicating that the differences between lichens on the tree groups tested were probably actual ecological phenomena. In both cases, the groups of trees tested were between (i) trees native to the study area and elsewhere on the Australian mainland, and (ii) trees whose biogeographical origins are not on the Australian mainland. In Table 4.3d, all individual trees were analysed, and in Table 4.3e all species were analysed. This is a highly interesting finding as it indicates that trees native to Australia have less probability of having lichen cover than those introduced from elsewhere. There are a number of possibilities as to why this statistically significant finding exists. In terms of this research, the following are possible explanations:

- The bark properties of Australian natives provide less suitable habitats than trees from elsewhere. Some support for this possible explanation is provided later in this chapter where it is shown that trees which shed bark, a common property amongst some Eucalypts, are poor hosts to lichens (Section 4.6.3). Other bark properties (roughness and pH, Section 4.6)) do not have the explanatory power of bark shedding, and there are no clear differences between Australian natives and those from elsewhere in the world. Neither are there significant differences in trees diameter and heights between native and non-native trees.
- Another, more intriguing, possibility is that lichens were introduced to the study area on trees from elsewhere in world that were planted as ornamentals and that as they are dispersing they are finding new, native tree, hosts. These could have been introduced by earlier settlers, but it is more likely that they were introduced on nursery stock when townships undertook tree planting. This was often done to celebrate or commemorate and in one township sampled, Port Germein, all the trees sampled were planted in the late 1940s to commemorate soldiers killed in World War II. This is potentially fruitful area for research which could combine local history studies with genetic analysis. Unfortunately, these findings came too late in the research for this type of investigation to be incorporated in the thesis.

None of the tests comparing (i) trees native to the study area, and (ii) trees native to elsewhere in Australia and those whose origins are not on the Australian mainland were significant; nor were any tests where species and genera were tested. In the latter tests, genera refer to trees which could only be identified to genus level.

4.5 Tree diameter, height and age

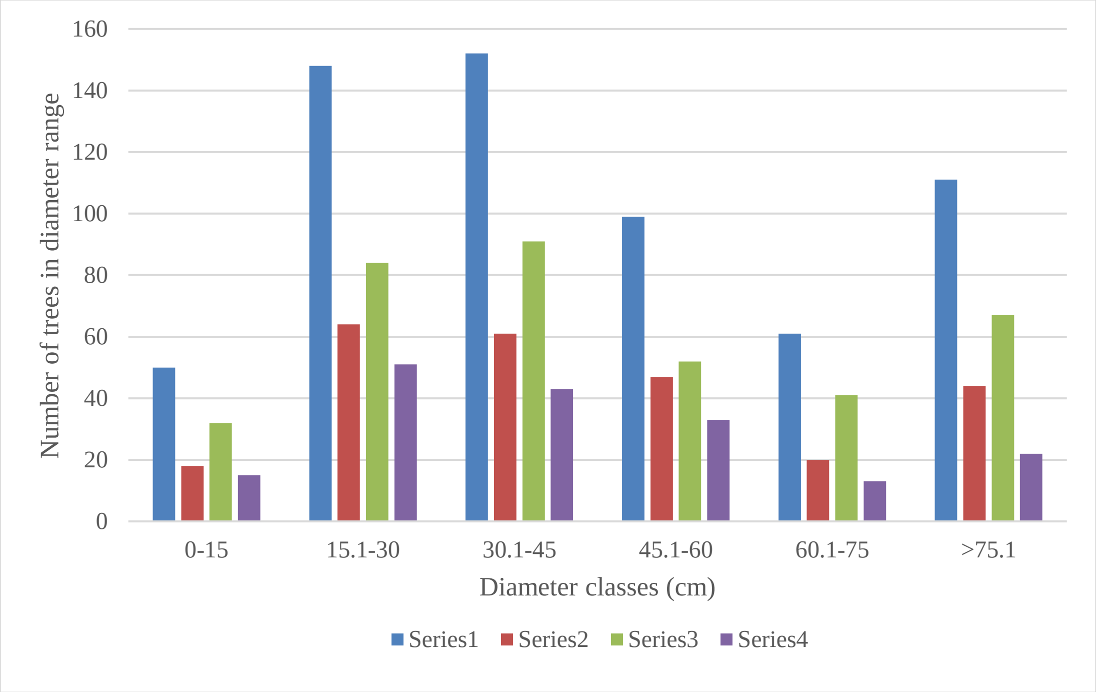
Tree diameter and height have been used as surrogates for tree age (Section 2.5.3). Tree allometric studies show that age is related to tree diameter and height, i.e., as trees grow they get taller and the girth of their trunks increases. However, it must be borne in mind that different tree species grow at different rates, and that growth rates depend on site conditions. Research by others has focused on relationships between trunk properties and lichen frequency, cover and lichen species richness; this research reports on percentage cover as the lichen variable.

4.5.1 Tree diameter

Trunk diameter has been studied in relation to tree age and lichen occurrence (Burgaz *et al.*, 1994b; Burgaz *et al.*, 1994a; Uliczka & Angelstam, 1999; Boudreault *et al.*, 2000; Cáceres *et al.*, 2007; Amo de Paz & Burgaz, 2009; Dittrich *et al.*, 2013; Rosabal *et al.*, 2013).

Tree diameters in this study ranged from 5 to 330cm. The 621 trees were sorted into six diameter classes: <15cm, 15.1-30cm, 30.1-45cm, 45.1-60cm, 60.1-75cm and >75.1cm. The majority of trees occurred in the 15.1-30cm and

30.1-45cm classes, and the least in the <15.1cm class (Series 1, Figure 4.8). In addition, all of these trees were sorted into three lichen occurrence groups: trees with lichens, trees without lichens, and trees with *X. parietina* — the most frequently occurring lichen. These are represented by Series 2, 3 and 4 respectively in Figure 4.8.



Series 1: All trees; Series 2: Trees with lichens; Series 3: Trees without lichens; Series 4: Trees with X. *parietina.*

Fig. 4.8 The relationship between tree diameter classes and lichen occurrence groups.

If the frequencies are considered, the rank order of trees without lichens (Series 3) is the same as for all trees (Series 1). Whereas the rank order of trees with lichens (Series 2) was marginally different to all trees in that it peaked in the 15.1-30cm diameter class while the 'all trees grouped' peaked in the 31.1-45cm class. This slight difference in distribution also existed between trees with *X. parietina* and all trees. Overall, lichens appear to be relatively independent of diameter class, and there was no evidence of increased lichen occurrence on older trees. However, there is the possibility of a slight dependency between lichen occurrence with tree diameter. The evidence for this can be seen in the 30.1-45cm diameter class, where trees with lichens appear to be under-represented compared to other diameter classes, and the 45.1-5-60cm class where they appear to be over-represented. These distributions were tested using χ^2, but no significant differences were found between the number of trees with and without lichens when tested against diameter classes ($\chi^2 = 3.56$, $p = 0.469$).

Berg *et al.* (1994), Kleczka and Angels team (1994) and Rosabal *et al.* (2013) found that older trees had higher lichen species richness; and many authors have indicated that more lichens are found on older trees (Almborn, 1948; Yarranton, 1972; Rogers, 1988; Thor, 1998; Uliczka & Angelstam, 1999; Boudreault *et al.*, 2000; Kantvilas & Jarman, 2004). Johansson *et al.* (2007), who used diameter to estimate tree age, found that lichen species richness did not increase on trees >65 years old. However, there is counter-evidence. Vinayaka *et al.* (2011) found that more lichens occurred on trees <25cm in diameter that on trees with greater girths. The data presented in Figure 4.8 does not provide any evidence for lichen occurrence being greater on older or on younger trees (using diameter as a surrogate for age). Wolseley and Aguirre-Hudson (1997), Rolstad and Rolstad (1999) and Snäll *et al.* (2003) also did not find relationships with tree age, which is in line with the statistical evidence from this research. But it would not be correct to say unambiguously that there is no relationship, as there is slight evidence that incidence of lichen occurrence peaks between 15.1 and 45cm.

Table 4.4 used data from all species at the 37 sample sites sampled. However, as different species of trees have different growth rates, this leads to unresolved questions about tree diameter-tree age relationships. Some researchers have focussed on a single tree species when researching lichen. For example, Ranius *et al.* (2008) and Örjan *et al.* (2008) stated that tree age was the most important determinant of species richness on beech trees. Kuusinen and Siitonen (1998) found older specimens of *Picea abies* carried more corticolous lichens than younger trees, and Kantvilas and Jarman (2004) found old specimens of *Eucalyptus obliqua* had heavy lichens loads. Two studies have shown that lichen occurrence may be related to particular ranges of diameters. Cobanoglu and Sevgi (2009) found that lichen richness on *Cedrus libani* was greatest of trees with diameters between 30 and 45cm.

The relationships between lichen cover and diameter were examined for three of the ‘tree groups’ that had the most individuals in this research: combined *Callistemon viminalis* “*Harkness*” and *Callistemon* sp. (Figure 4.9), *Eucalyptus torquata (*Figure 4.10), and combined *Fraxinus angustifolia and F. excelsior* (Figure 4.11).

The combined *Callistemon viminalis* “Harkness” and *Callistemon* sp. class clearly showed an increase in lichen occurrence with increasing diameter up to 45cm, after which the incidence of trees with lichens dropped markedly, even though the number of trees was greater in the 45.1-60cm class.

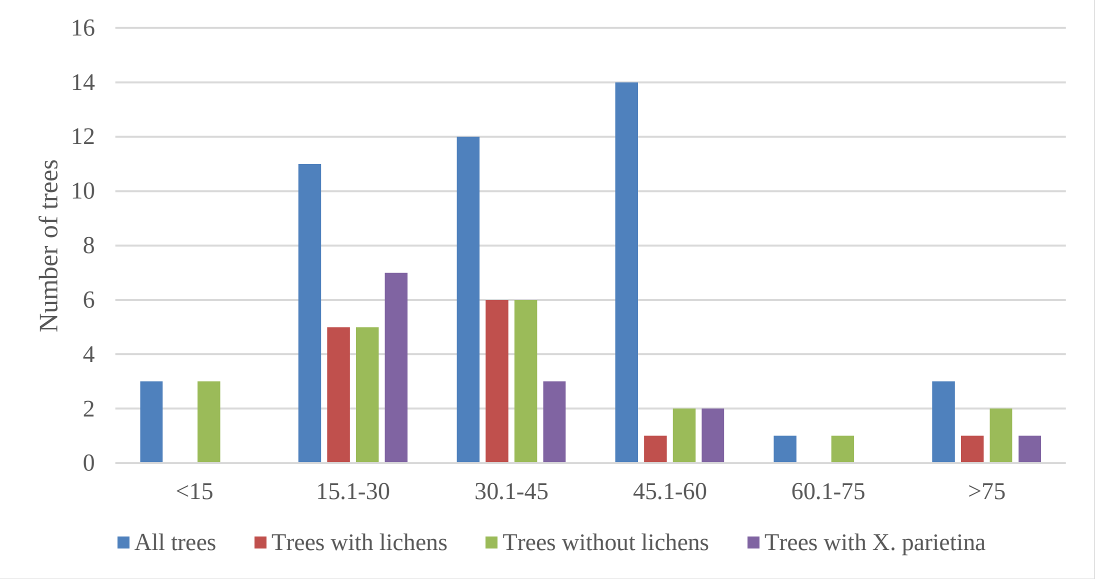


Fig. 4.9 The relationship between tree diameter class and lichen occurrence for the Callistemon 'tree group'.

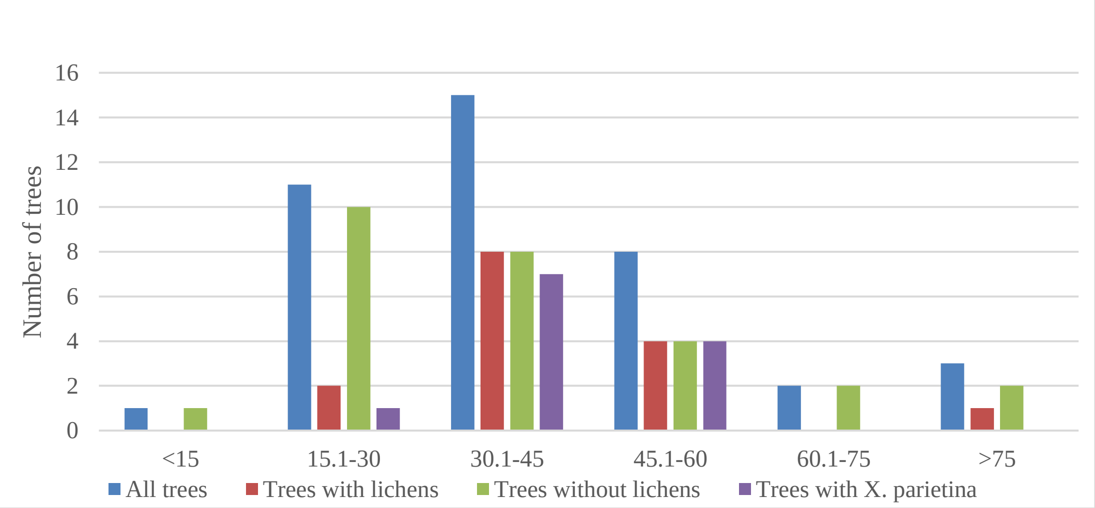


Fig. 4.10 The relationship between tree diameter class and lichen occurrence for the *E. torquata* 'tree group'.

The *E. torquata* tree group showed a clear increase in lichen occurrence with increasing tree diameter up to 45cm, after which the number of trees with lichens dropped significantly. No lichens were found on the trees with diameters between 60.1 and 75cm.

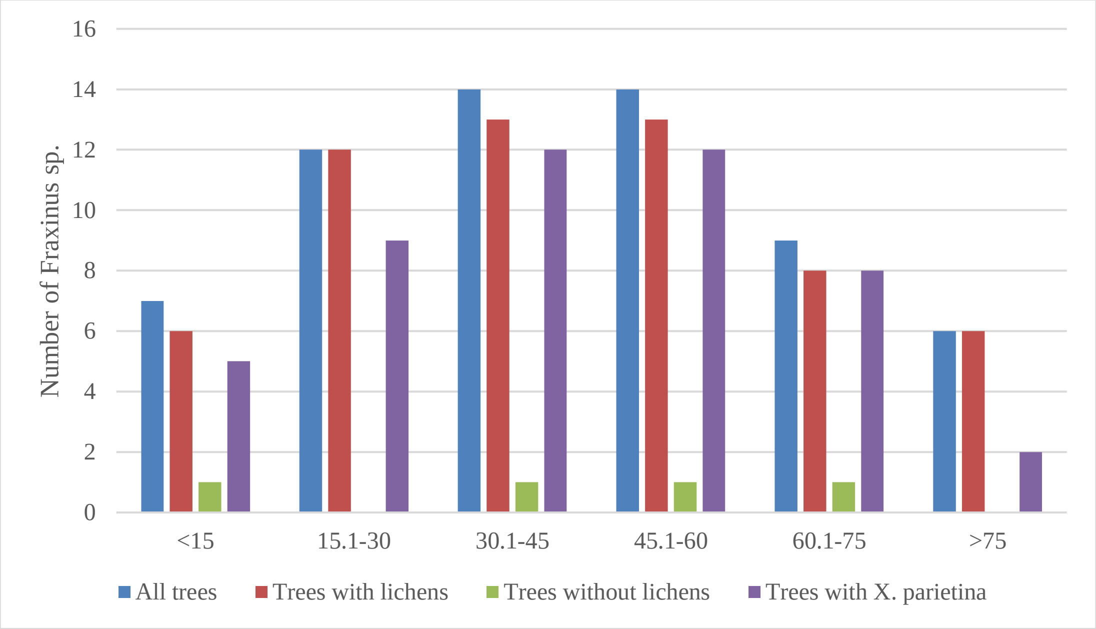


Fig. 4.11 The relationship between tree diameter class and lichen occurrence for the combined Fraxinus 'tree group'.

The combined Fraxinus class showed an increase in lichen occurrence with increasing diameter between 15.1 and 60cm, after which the number of trees with lichens dropped significantly. The relationship was similar for the occurrence of *X. parietina* and *Fraxinus* sp. trees (the most frequently occurring lichen species-tree genus association in the study). Johansson *et al.* (2007) noted a positive association between total species richness and tree age on *F. excelsior*, which is partly borne out by this study. However, despite the change in absolute number of trees with lichens, the ratio of trees with lichen to all trees varies little in Figure 4.11 and ratio in the largest class is 1:1.

4.5.2 Tree height

The relationships between tree height and lichen occurrence were also investigated. These analyses were based in part on research conducted by

Fanning *et al.* (2007), who found that lichen richness and the distribution of lichen growth forms were influenced by both tree species and canopy height; and McCune *et al.* (2000) who observed similar relationships.

The height to the top of the canopy, or tree height, in this study ranged from 2.45m for a specimen of *E. torquata* at Terowie to 29.5m for two trees at Mylor — specimens of *Cupressus* sp. and *Populus nigra italia.* The 621 trees were sorted into four height classes: <5m, 5.1-10m, 10.1-20m, and >20.1cm (Figure 4.12). The majority of trees were almost evenly split between the 5.1-10m and 10.1-20m classes. The trees were again sorted into three groups: trees with lichens, trees without lichens, and trees with *X. parietina*.

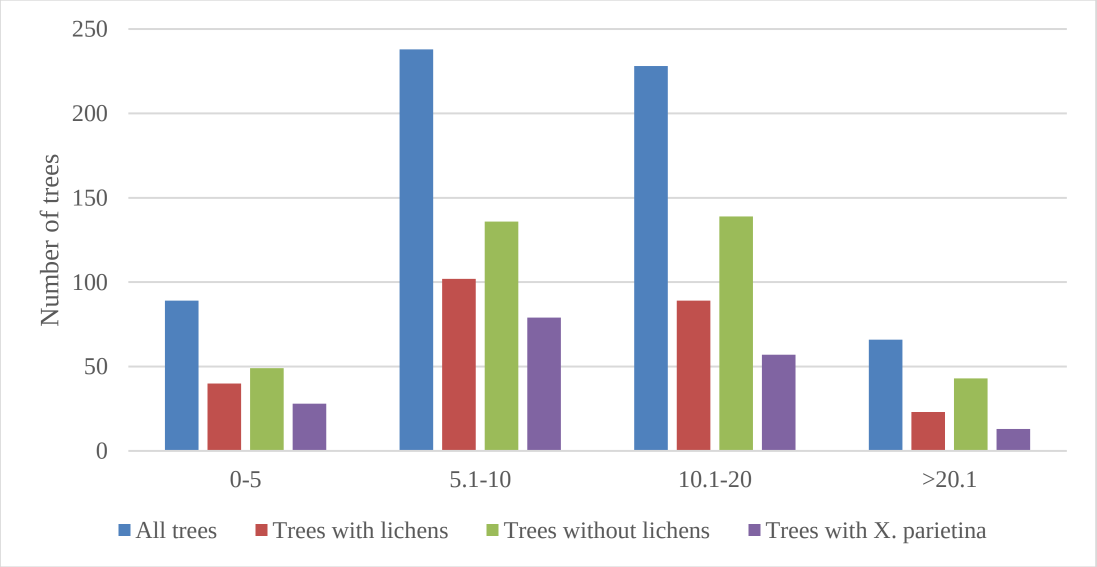


Fig. 4.12 The relationship between tree height class and lichen occurrence groups.

Most lichens occurred on trees with heights between 5.1-10m. Using tree height as an age surrogate, the lichen occurrence does not exhibit a tendency to increase with age (Figure 4.12). Lichen occurrence was plotted against tree height for the three ‘tree groups’ to see if lichen occurrence was related to trunk height for these genera/species (Figures 4.13-4.15). However, if trees with lichens are expressed as a proportion of all trees then there is a slight decline as the height class increases.

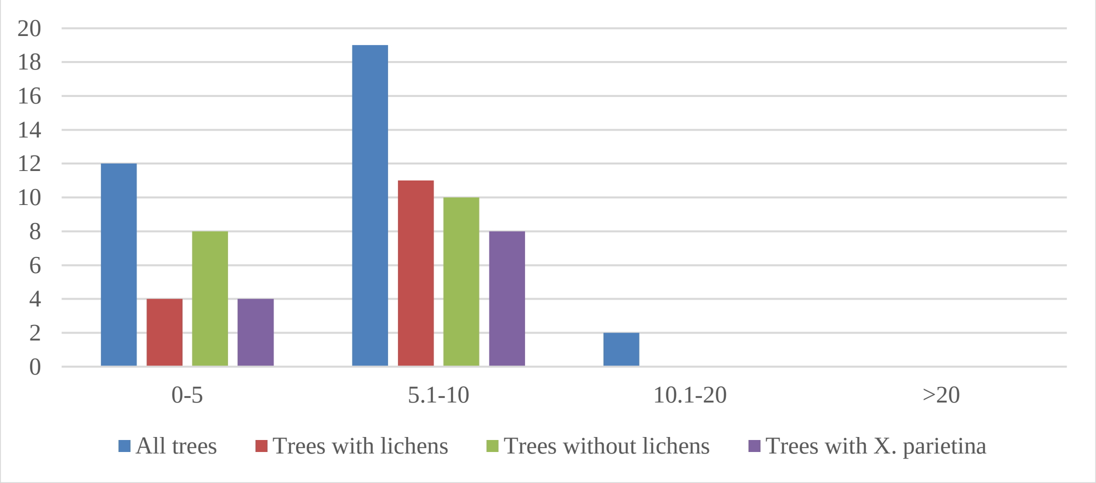


Fig. 4.13 The relationship between tree height class and lichen occurrence group for the combined *Callistemon* ‘tree group’.

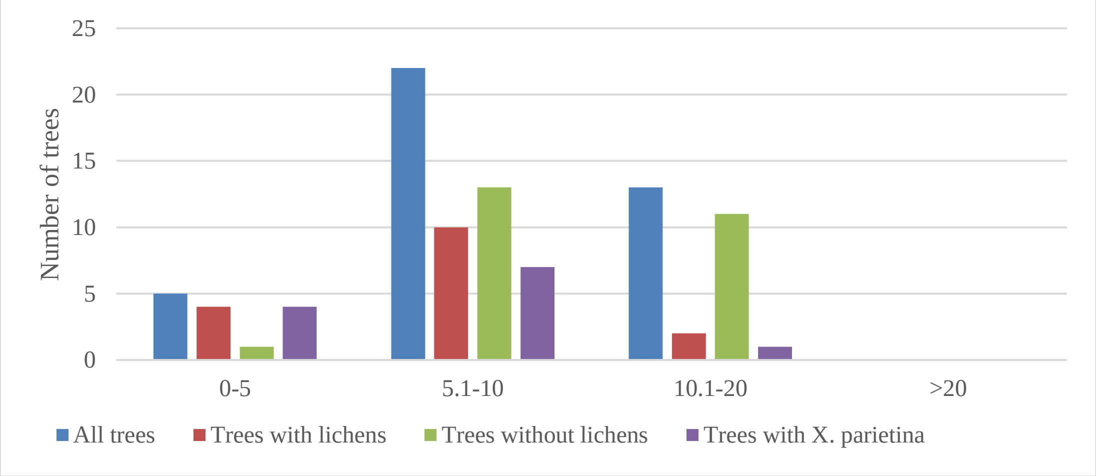


Fig. 4.14 The relationship between tree height class and lichen occurrence group for the *E. torquata* ‘tree group’.

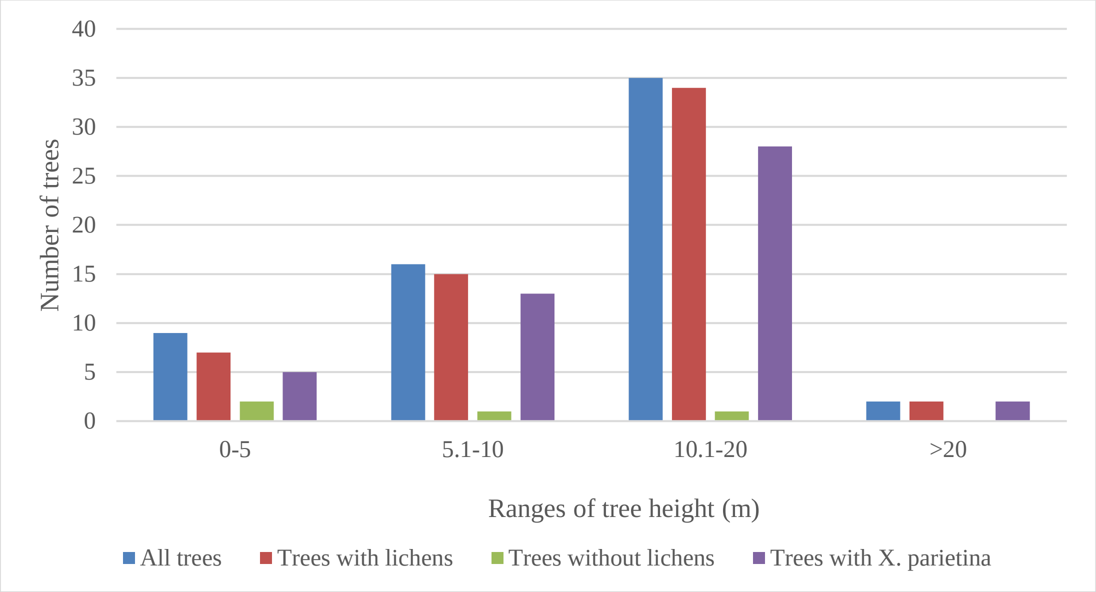


Fig. 4.15 The relationship between tree height class and lichen occurrence group for the combined *Fraxinus* 'tree group'.

The occurrence of trees with lichens and trees with *X. parietina* in the three 'tree groups' shown in Figures 4.13-4.15 showed similar trends to those for all lichens on all trees (Figure 4.12), i.e., the ratio of trees with lichens paralleled the number of trees in each class. This again indicates that lichen occurrence is likely to be independent of age (using tree height as an age surrogate) and is in line with the findings when tree diameter was used as a surrogate for tree age earlier in this section. Therefore, it is clear from these two tests, that lichen occurrence is likely to be independent of tree age in the study area.

4.6 Bark properties

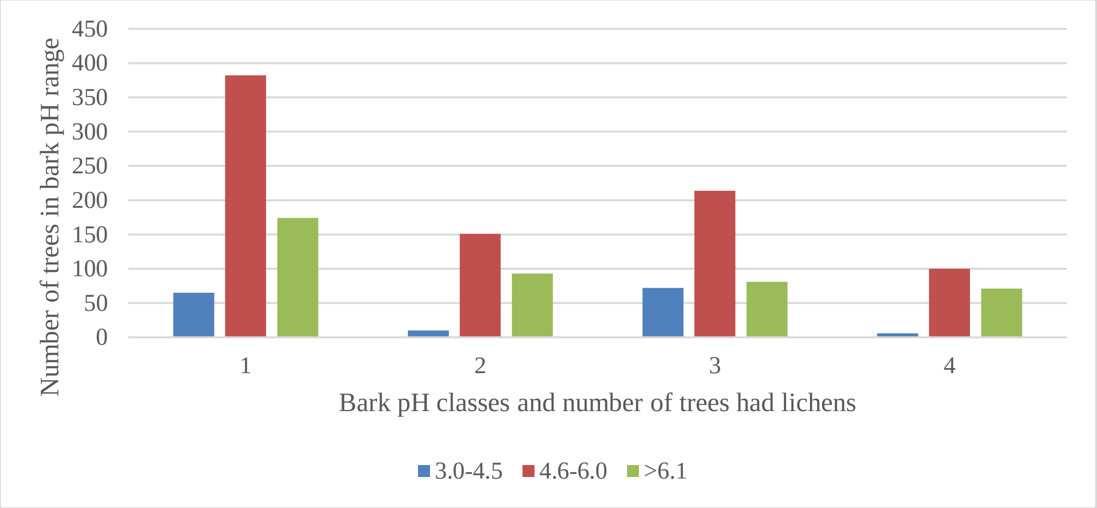
Bark properties such as texture, water-retention capacity and bark chemistry have been cited as influences on the distribution of corticolous lichens. In this study, three bark parameters were analysed: bark pH, a robust reductionist approach to measure bark chemistry which has been used by Culberson

(1955), Rogers (1992), James *et al.* (1997), Wolseley and Aguirre-Hudson (1997), Cáceres *et al.* (2007) and Rosabal *et al.* (2013);

- bark roughness, which has been found to influence lichen frequency elsewhere (Culberson, 1955; Wolseley & Aguirre-Hudson, 1997; Vinayaka *et al.*, 2011); and
- bark shedding, the choice of which is supported by Kantvilas and Jarman (2004) who noted that the bark shedding behaviour of many *Eucalyptus* species in Tasmania affected the occurrence of corticolous lichens.

4.6.1 Bark pH

Bark pH is a frequently measured bark parameter in lichen ecology studies (James *et al.*, 1977; Rogers, 1992; Wolseley & Aguirre-Hudson, 1997; Cáceres *et al.*, 2007; Rosabal *et al.*, 2013). In this study bark pH ranged from 3.13 to 7.80. The lowest value was for the sole individual of *Indigofera australis* — which did not have lichens and the highest was for an individual of *Pinus halepensis* sampled at Lyndoch. It also had no lichens. The trees were grouped into three pH classes: 3.0-4.5; 4.6-6.0 and >6.1 and plotted against the lichen occurrence groups used earlier (Figure 4.16).



Group 1: All trees; Group 2: Trees with lichens; Group 3: Trees without lichens; Group 4: Trees with X. *parietina*

Fig. 4.16 Relationships between bark pH class and lichen occurrence on all trees.

The bark pH of the majority of the 621 trees sampled was in the range 4.6-6.0. The lowest number of trees were in the most acidic bark class (pH = 3.0-4.5). The distribution of the number of trees, the number of trees with and without lichens, and the number of trees with *X. parietina* are very similar (Figure 4.16). Most trees with lichens and *X. parietina* were found in the intermediate class with slightly acid bark. Very few trees with bark pH below 4.5 had lichen growth.

Pearson product moment correlations were conducted on lichen cover and bark pH (Table 4.5). This test was able to be used as the data were continuous, and because of the high number of samples normal distributions of both bark pH and lichen cover could be assumed. Pallant (2007) and Ghasemi and Zahediasl (2012) indicate that if sample size is >30-40, normality assumptions are probably not violated in statistical testing. This indicates that parametric rather than non-parametric correlation methods can be used on these data (Elliott & Woodward, 2007). In fact if there are hundreds of samples, as is the case with all trees sampled (621), data distribution does not need to be considered at all in statistics (Altman & Bland, 1995).

Table 4.5 Summary of correlation analyses between bark pH and lichen cover.

Sample	Number of trees in sample	R	Significance, 2-tailed test
All trees	621	+0.148	Significant at 0.01
Trees with lichens	229	+0.098	Not significant
Trees with *X. parietena*	165	+0.087	Not significant

The only significant correlation reported in Table 4.4 was the very weakly positive relationships between lichen cover and bark pH for all trees. This tied in with the data presented in Figure 4.16, in which the distribution of lichens mirrored the distribution of trees in having a distinct break in lichen cover on trees between the acidic and weakly acidic pH classes. James *et al.* (1977), Rogers (1992), Wolseley and Aguirre-Hudson (1997) and Rosabal *et al.* (2013) found that lichen cover increases with an increase in bark pH and this study weakly supports their findings. More importantly, perhaps, this is the first study from arid and semi-arid environments to provide some confirmation of this relationship.

4.6.2 Bark roughness

Gradstein *et al.* (1996), Cáceres *et al.* (2007), Rosabal *et al.* (2012) and Rosabal *et al.* (2013) have noted the importance of bark roughness as a control on lichen growth. Bark roughness measurements were grouped into five classes: 0-1mm, 1.1-5mm, 5.1-10mm, 10.1-20mm and >20.1mm and the tree groups used previously were plotted for these classes (Figure 4.17).

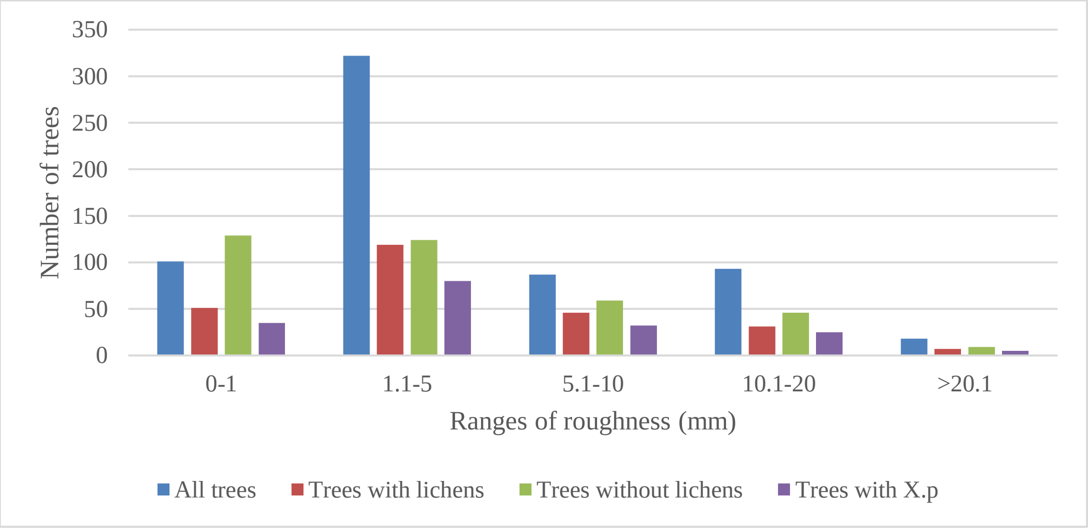


Fig. 4.17 Relationships between bark roughness classes and lichen occurrence.

The distribution of all trees by roughness class peaked in the 1.1-5mm class, with approximately similar numbers of trees, 83-100, in all other classes except the >20.1mm class. The number of trees with lichens (Series 2, Figure 4.17) showed a somewhat similar pattern; though there was a clear tendency for the number of trees with lichens to decrease from the 5.1-10mm class to the >20.1 class. This was a trend that was not seen in all trees, but one which did appear in trees with *X. parietina.* The number of trees without lichens also showed a difference when compared to all trees, i.e., the trees without lichens were over-represented in the 0-1mm class. This was because this class contains the trees that have recently shed bark and these substrates have not yet been colonised by lichens.

These data were also analysed using Pearson product moment correlation (Table 4.6). Two associations are significantly, but very weakly, negative. These are between bark roughness and lichen cover on all trees, and between bark roughness and lichen cover on trees with lichens. These results indicate the possibility of a weak trend toward reduced lichen cover as bark roughness increases. However, this trend is weaker than the author anticipated it wpuld be after sampling lichens on all 621 trees.

Table 4.6 Summary of correlation analyses between bark roughness and lichen cover.

Sample	Number of trees in sample	R	Significance, two-tailed test
All trees	621	-0.026	Significant at 0.05
Trees with lichens	229	-0.124	Significant at 0.01
Trees with *X. parietina*	165	-0.032	Not significant

It is also probable that a rougher bark increases water retention capacity of bark, which creates moister microclimates that are more favourable for lichen growth. This may be particularly useful in arid and semi-arid environments. Cáceres *et al.* (2007) divided bark roughness into four classes: (i) smooth bark with shallow lenticels; (ii) rough bark with small, dense lenticels; (iii) uneven bark with large lenticels; and (iv) partly cracked bark lacking lenticels. Wolseley and Aguirre-Hudson (1997) noted more lichens on smoother bark than rougher bark trees, which is different to the findings in this research.

4.6.3 Bark shedding

Very few researchers have considered the stability of bark substrates when examining the distribution of corticolous lichens, though Kantvilas and Jarman (2004) noted that bark shedding in some Eucalypts in Tasmania influenced lichen growth. Trees which had recently shed, or were shedding, their bark were recorded on the field sheets in this research (Section 3.3.2) as it was anticipated that a relationship between lichens and bark shedding would exist in the study area. The relationship between lichen occurrence and bark shedding are in the form of a 2x2 contingency table (Table 4.7).

Table 4.7 Contingency table of lichen occurrence and tree shedding characteristics.

Tree type		Lichens present	Lichens not present
Shedding	Observed	25	138
	Expected	*66.41*	*96.59*
Not shedding	Observed	228	230
	Expected	*186.59*	*271.41*

A χ^2 analysis for association (again the Yates test adjusted for continuity was employed) was carried out on these data. This yielded a Φ coefficient of +0.31, χ^2 of 57.66 which is significant at 99% ($p = <0.0001$). Both Fisher exact tests (one- and two-tailed) were significant at $p = <0.0001$. This analysis indicates a very strong relationship between bark stability and lichen growth, as was anticipated.

4.7 Summary

Five corticolous macrolichen species — *Xanthoria parietina*, the *Caloplaca* *holocarpa* group, *Physica aipolia*, *Lecidella elaeochroma* and *Chrysothrix xanthina* — were found in the study area of approximately 22,220 km^2. Lichen species richness varied from 0 to 3 lichens per tree. Only 5.12% of trees sampled had two or three lichens. These 32 individuals comprised a relatively high number of *Celtis australis* and *Melia azedarach*. It is not clear if this is due to the properties of these tree species or the limited number of sites where these lichen-infested trees grow.

There is evidence that the probability of lichens growing on introduced trees is higher than lichens growing on species native to the Australian mainland, from contingency table analysis of all individuals sampled, as well as all species sampled. This is a potentially important finding, and requires further research to verify this, and if it is confirmed, to explain how this dichotomy arises. Initial thoughts are that this may either be due to differences in bark properties between these two groups of trees, or that lichens were introduced on ornamental exotic trees and are now dispersing into the local tree flora.

Lichens sampled across all sites in the study area appeared to be relatively independent of tree diameter class. There was no clear age-dependent relationship, although lichen occurrence did peak between tree diameters of 15.1 and 45cm. Lichen occurrence was also independent of tree height. These two findings taken together indicate that lichen occurrence is independent of tree age for all trees and for *Callistemon* sp., *Fraxinus* sp. and *E. torquata.*

Three bark properties showed different influences on lichen occurrence, though these were not always supported by statistical testing. Lichen cover increased with increasing bark pH. Lichens were rare on highly acidic bark. Bark shedding was strongly related to lichen occurrence, and it was clear that the five macrolichens sampled preferred stable bark surfaces. Bark shedding is related to bark roughness in that trees that have recently shed bark are smooth, they are also almost free of lichens, However, the relationship between bark roughness and lichen occurrence and cover was less clear than that for bark pH or bark shedding.

This chapter has thoroughly discussed the relationships between trees and corticolous lichens. The following chapter will present and analyse the empirical data related to lichen-climate relationships in the study area in a similar way to the lichen-bark relationships in this chapter.

CHAPTER FIVE

CLIMATE-EPIPHYTIC LICHEN RELATIONSHIPS

5.1 Introduction

The research in this chapter builds on other studies that have examined the influences of climate on lichen distribution on a wide variety of substrates, which was reviewed in Sections 2.5.1 and 2.5.2, in particular corticolous lichens. The main foci of the chapter are the relationships between tree microclimate and the occurrence of corticolous lichens (Section 5.2) and the influences of regional microclimate across the Mid North, Southern Flinders Ranges and Adelaide Hills on corticolous lichens on trees at 37 study sites (Section 3.2). An assumption that was implicit in sampling (Section 3.2) was that the microclimates of the study sites in each township have no significant internal variations, and therefore any influences of climate variability in study sites on lichen distribution is not discussed.

5.2 Tree microclimate

There are two elements to tree microclimate in this research. First, the distribution of lichens on tree trunks; where aspect is used as a surrogate for the different elements of microclimate, in particular incident solar radiation and relative humidity. Second, a comparison of lichen occurrence between tree canopies and tree trunks, which has recently been identified as important by Kiebacher *et al.* (2016), but has rarely been studied before.

5.2.1 Trunk microclimate

Lichen occurrence was measured on the north, east, south and west (N, E, S, W) aspects of the 621 trees sampled using the grid method (Section 3.2) at all 37 sites (Table 3.1).

The Kruskal-Wallis H test was used to reveal statistically significant differences in lichen occurrence between the four aspects as the data are not normally distributed (Clarke, 1994; Ennos, 2000; Wheater & Cook, 2000). The test was carried out for all lichens, and for *Xanthoria parietina* and *Caloplaca holocarpa* — the two most frequently occurring species in the study area – individually. Dunn's nonparametric comparison for *post hoc* testing was used to analyse which aspects were significantly different in each case.

However, before testing for differences in lichen occurrence, the 37 sample sites were grouped into three classes (low-, medium- and high-rainfall) for these tests based on natural breaks in a histogram of their mean annual rainfall values (Table 5.1, Fig. 5.1). The rainfall data used were SILO data based on Australian Bureau of Meteorology records between 1985 and 2015 (Section 3.3). Mean annual rainfall ranged from 252.8mm at Port Augusta to 995.4mm at Stirling. Mean annual rainfall of the low rainfall sites ranged from 252.8mm (Port Augusta) to 343.0mm (Orroroo). For the medium rainfall sites the range was 398.2mm (Two Wells) to 554.3mm (Angaston) and all the high rainfall sites had mean annual rainfall >647.7mm.

Table 5.1 Study sites grouped into mean annual rainfall (1985-2015) classes.

Low rainfall sites	Mean annual rainfall (mm)	Medium rainfall sites	Mean annual rainfall (mm)	High rainfall sites	Mean annual rainfall (mm)
Port Augusta	252.8	Two Wells	398.2	Clare	647.7
Carrieton	308.1	Crystal Brook	401.8	Springton	651.8
Port Wakefield	315.8	Spalding	408.5	Williamstown	666.3
Snowtown	317.4	Burra	429.4	Mount Barker	721.0
Hawker	325.4	Hallett	436.6	Macclesfield	733.8
Terowie	332.1	Gawler	442.9	Gumeracha	739.3
Peterborough	332.9	Jamestown	453.9	Meadows	819.1
Oodla Wirra	333.4	Tarlee	463.9	Lobethal	889.0
Port Germein	334.5	Eudunda	466.2	Bridgewater	940.9
Robertstown	338.6	Freeling	475.9	Mylor	972.3
Orroroo	343.0	Truro	479.3	Stirling	995.4
		Rhynie	505.4		
		Auburn	545.5		
		Lyndoch	553.2		
		Angaston	554.3		

Source: Calculated from SILO data downloaded in 2018.

In addition to mean annual rainfall, Figure 5.1 also shows the mean summer (December, January, February) and winter (June, July, August) rainfall totals. While it can be posited generally that annual rainfall is positively correlated with lichen growth parameters (e.g., cover, frequency and diversity), to what extent summer and winter rainfall are influences is less well known. Ellis, Coppins, and Dawson (2007) noted that a seasonal drying trend in the northern hemisphere was a potential influence on lichen growth under some predicted climate change scenarios. Therefore, it may be hypothesised that summer rainfall, which ranges from 46.0mm at Port Augusta to 104.2mm at Stirling, could possibly to be a limiting factor in lichen growth in the study area. The extent to which this may be a limiting factor will, of course, also be influenced by the high summer temperatures and evaporation rates. However, mean winter rainfall, which ranges from 69.9mm at Port Augusta to 403.8mm at Stirling, is less easily conceptualised as a limiting factor because at that time of the year temperatures and evaporation rates are lower than in the summer and it is likely that a greater proportion of rainfall will be absorbed by lichens in terms of direct precipitation or stemflow down trunks.

Table 5.2, Row 1, shows that the differences in lichen cover between the four aspects for all trees sampled at all sites is statistically significant, $X^2(3) = 8.310$, $p = 0.040$, with mean rank lichen covers of 1206.75 (for the north aspect, N), 1218.54 (E), 1294.48 (S) and 1250.24 (W). Dunn's test revealed statistically significant differences between N and S ($p = 0.008$) and E and S aspects ($p = 0.023$).

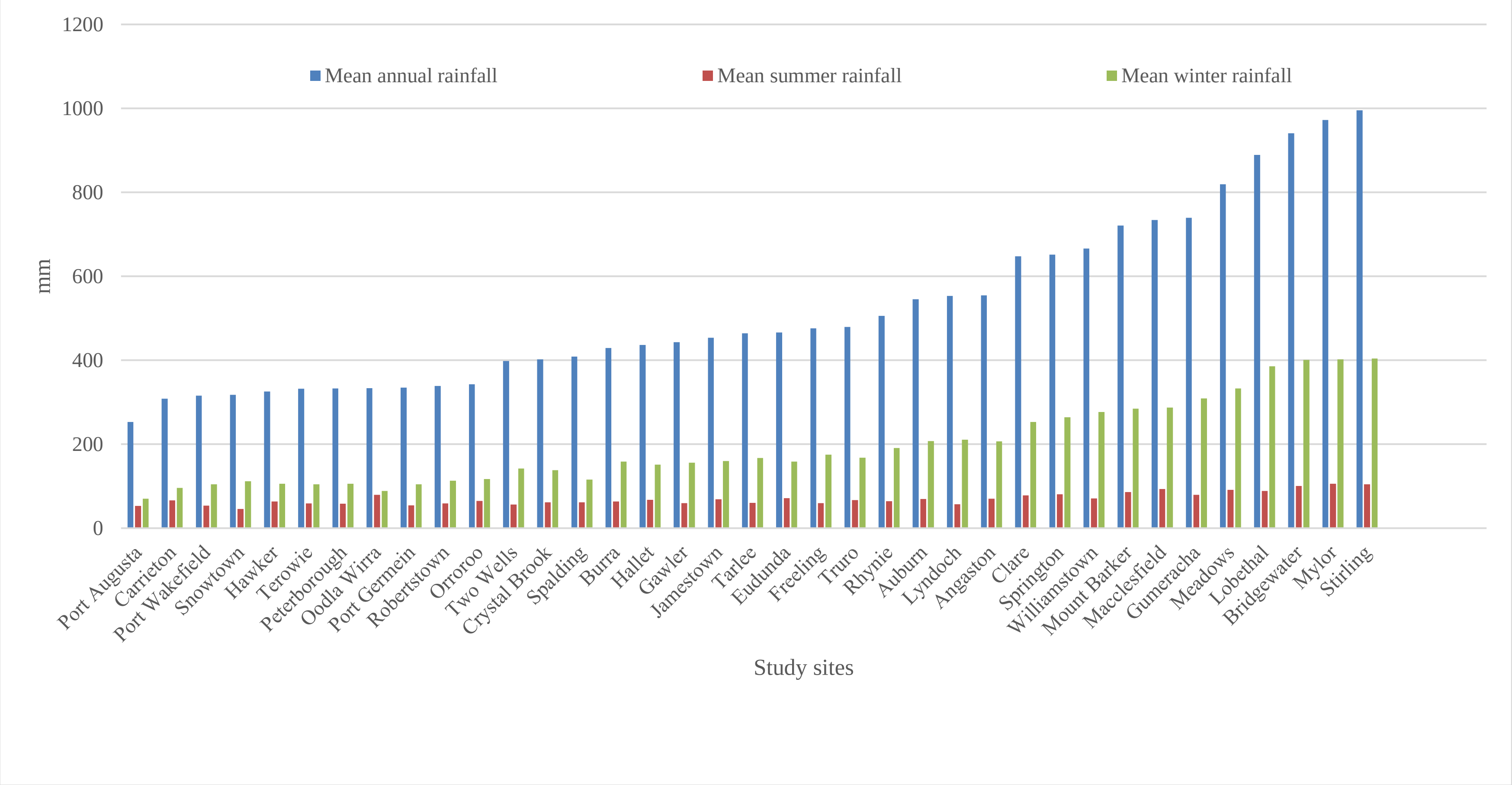


Fig. 5.1 Mean annual, summer and winter rainfall (1985-2015) at the study sites, ranked by mean annual rainfall. Source: Calculated from SILO data downloaded in 2018.

Table 5.2 Summary of Kruskal-Wallis H tests for differences in lichen cover on all trees, and trees with lichens at all sites and at high, medium and low rainfall sites.

All trees and sites			Mean rank			
	$X^2(3)$	*p*	N	E	S	W
All trees, all sites (n = 621)	8.310	0.040**	1206.75	1218.54	1294.48	1250.24
All trees with lichens, all sites (n = 254)	13.156	0.004**	463.72	472.14	547.76	494.38
All trees with lichens, high rainfall sites (n = 110)	1.382	0.710	199.91	197.98	214.13	197.98
All trees with lichens, medium rainfall sites (n = 94)	12.218	0.007**	195.63	198.34	246.65	225.38
All trees with lichens, low rainfall sites (n = 50)	11.137	0.011**	43.57	53.83	70.54	50.06

Each row tests the null hypothesis that the Aspect 1 and Aspect 2 distributions are the same. Results from asymptotic significances (2-sided tests) are displayed. The significance level is .05. ** Significant difference at *p* = 0.05; n: number of trees calculated

Statistically significant differences in lichen cover between the four aspects were also apparent, $X^2(3) = 13.156$, $p = 0.004$, for trees with lichens (Table 5.2). Mean rank lichen covers were 463.72 (N), 472.14 (E), 547.76 (S) and 494.38 (W). In this sample, statistically significant differences were found between the N and S, and E and S ($p = 0.001$ and 0.003 respectively) pairs of aspects using Dunn's test. Trees with lichens at high rainfall sites (Table 5.2) showed no statistically significant differences in lichen cover between the four aspects, $X^2(3) = 1.382$, $p = 0.710$. However, statistically significant differences were discovered at the medium ($X^2(3) = 12.218$, $p = 0.007$) and low ($X^2(3) = 11.137$, $p = 0.011$) rainfall sites (Table 5.2). Dunn's test showed that while there was only one statistically significant difference in lichen cover — between the N and S aspects – at the medium rainfall sites, there were significant differences between lichens at three pairs of aspects at the low rainfall sites (N and S, $p = 0.001$, W and S $p = 0.015$, and E and S, $p = 0.048$).

The same statistical tests were also used to examine the distribution of *X. parietina* (Table 5.3). There were statistically significant differences in *X. parietina* cover between aspects at all sites, $X^2(3) = 10.060$, $p = 0.018$ (Table 5.3), which Dunn's test revealed occurred between the N and S, E and S and W and S pairs of aspects (p = 0.006, 0.007 and 0.039 respectively). When the test was repeated for the sites grouped by rainfall classes, there were no statistically significant differences in lichen cover between the four pairs of aspects at high rainfall ($X^2(3) = 1.527$, $p = 0.676$) or low rainfall ($X^2(3) = 6.761$, $p = 0.08$) sites. However, there was a statistically significant difference in lichen cover between aspects ($X^2(3) = 8.185$, $p = 0.042$) at the medium rainfall sites, caused by significant differences between N and S ($p = 0.013$), E and S ($p = 0.016$) and W and S ($p = 0.048$) aspect pairs.

A similar analysis carried out on *C. holocarpa* did not reveal any statistically significant differences in lichen cover at either all sites nor at high, medium or low rainfall sites. The other three lichens sampled were not tested individually because of their low frequencies of occurrence.

Table 5.3 Summary of Kruskal-Wallis H tests for differences in *X. parietina* cover for all sites, and high, medium and low rainfall sites.

Sites			Mean rank			
	$X^2(3)$	*p*	N	E	S	W
Trees with *X. parietina,* all sites (n = 177)	10.060	0.018**	331.48	333.15	390.75	346.61
Trees with *X. parietina* at high rainfall sites (n = 76)	1.527	0.676	133.84	132.80	147.60	139.76
Trees with *X. parietina* at medium rainfall sites (n = 61)	8.185	0.042**	145.46	146.62	181.08	152.84
Trees with *X. parietina* at low rainfall sites (n = 40)	6.761	0.080	45.12	50.81	65.02	49.06

Each row tests the null hypothesis that the Aspect 1 and Aspect 2 distributions are the same. Results from asymptotic significances (2-sided tests) are displayed. The significance level is .05. ** Significant difference at *p* = 0.05; n: number of trees calculated

The results of the *post-hoc* Dunn's tests for all Kruskal-Wallis analyses reported in Table 5.2 and 5.3, and for *C. holocarpa*, are summarised in Table 5.4. The most frequently occurring significant differences in lichen cover on the same individuals are between the N and S aspects. If the high rainfall sites, where no significant differences were recorded, and for *C. holocarpa* are omitted: six of a possible eight N-S pairs (75%) are significantly different. Again, after omitting the high rainfall sites and *C. holocarpa,* 13 out of 32 aspect pairings (40.6%) were significantly different. All of these significantly different pairs included the south aspect.

Table 5.4 Significant differences in lichen occurrence by trunk aspect pairs.

	All sites, all trees	Only trees with lichens	Low rainfall sites	Medium rainfall sites	High rainfall sites
All lichens	N and S E and S	N and S E and S	N and S E and S W and S	N and S	None
X. parietina	n/a	N and S E and S W and S	None	N and S W and S	None
C. holocarpa	n/a	None	None	None	None

These findings indicate that all lichens and *X. parietina* were more likely to be found growing on the southern aspects of tree trunks over the entire study area, followed by the eastern aspects. One inference that can be drawn from this is that all of the lichens sampled in research grow better on the cooler and moister microclimates of the southern and eastern aspects of tree trunks than they do on the warmer and drier northern and western aspects. The absence of any significant differences in lichen occurrence on any pairs of aspects at high rainfall sites (Table 5.4) supports this inference because the magnitude of such microclimatic differences is likely to decrease with increasing rainfall. A second inference is that this difference arises in part because southern and eastern aspects receive less incident solar radiation than the other two aspects. As the majority of the canopies of the trees sampled are very open and are situated relatively high in terms of a tree's overall structure, the receipt of solar radiation on the lower trunks (where measurements were made) will be relatively unrestricted by canopies. This will accentuate differences in incident solar radiation and trunk surface temperatures between the four trunk aspects. Given this, it is likely that if NE, SE, SW and NE aspects had been sampled, the SE aspect may have revealed even stronger statistical differences when paired with the other three aspects as has been found elsewhere in Australia (Prof. Jamie Kirkpatrick, University of Tasmania, personal communication, 2017).

These findings correspond with observations from the northern hemisphere (though their northern aspects have greater lichen coverage than southern aspects) and the fact that 75% of N-S pairs — which represent the greatest contrast in solar radiation in this study – were significantly different. The climate in the study area is similar to those at the 34 sites in Anatolia, Turkey researched by Cobanoglu and Sevgi (2009) who found that epiphytic lichen frequency was greater on north-facing than on south-facing slopes. By way of contrast, Rosabal *et al.* (2010) found that lichen frequency did not vary significantly with aspect on tree trunks in wetter tropical montane rainforests in Cuba. Their findings lend some support to the fact that no statistically significant relationships were found between lichen occurrence on different trunks aspects at the wetter sites in this research. They also noted the importance of light penetration in determining lichen growth. This supports the role that the incidence of solar radiation may have on trunk lichen growth in the study area where the trees sampled were often individuals (e.g., ornamental trees planted in reserves or street trees) or rows of trees along creek lines. The ‘woodland’ structure at all sites sampled could therefore be described as very open. This will allow high amounts of incident light to reach the trunks, regardless of aspect, compared to dense forests. In addition, these open structures allow air to be blown between trees relatively unimpeded; which will lead to relatively high rates of evaporation of moisture on the bark and lichens, and accentuate evapotranspiration from the photobiont in the lichen. In sum, all of these microclimate factors are likely to accentuate differences in microclimate according to trunk aspect (Tables 5.2-5.4), as would be the case in semi-arid forests in Anatolia (Cobanoglu & Sevgi, 2009) rather than in the Cuban rain forests sampled by Rosabal *et al.* (2012).

Nash (2008) argued that lichens grew better in the areas with high moisture levels and that their growth is more restricted in dry regions. These observations made in this research support this generalisation. In the Adelaide Hills — which has a relatively wet, warm temperate climate – lichen growth is more prolific than in the semi-arid and arid Mid North and Southern Flinders Ranges. The occurrence of lichens is more similar on the different trunk aspects in the Adelaide Hills than in other parts of the study area (Tables 5.2-5.4). At the drier sites, in the Mid North and Southern Flinders Ranges, precipitation appears to become more of a constraint on lichen growth and, the differences between the southern and eastern aspects and the drier northern and western aspects leads to significant differences in lichen frequency (Tables 5.2-5.4). However, this cannot be entirely explained in terms of precipitation. Temperature and evaporation are likely to be important influences; they will be explored in Section 5.3.

5.2.2 Lichens in canopies

Epiphytic lichens were found often growing in tree canopies as well as on the trunks of the trees. Occasionally lichens occurred in the canopies but not on the trunks of individual trees and vice versa. Canopy lichen measurements were added to the research project after a pre-publication copy of Kiebacher *et al.* (2016)’s study on canopy lichens became available. By the time I had read this paper I was unable to develop a quantitative method to measure lichens on the canopy because of time and financial constraints. However, I was able to make presence and absence measurements of canopy lichens for each tree (Section 3.2) at the sites still to be sampled. I also revisited sites which had been sampled to make additional canopy lichen assessments.

Table 5.5 provides data on the frequency of the occurrence of trunk and canopy lichens at each study site. The occurrence of trunk and canopy lichens is significantly different when all study sites are compared (Wilcoxson signed-rank test, two-tailed: W = 123, p <0.05; z = -2.0434, p = 0.04136). The Freeling, Gumeracha, Lobethal and Springton sites each had >65% of trees with trunk lichens. These four sites also had >60% of trees with canopy lichens. However, there were other sites with fewer trees with less trunk lichens that had >60% of trees with canopy lichens. These were Stirling (69.6%; ranked 7th in trunk lichen frequency), Mount Barker (60.9%; 9th trunk lichen frequency), Mylor (91.3%, the highest frequency of canopy lichens; 14th trunk lichen frequency), and Macclesfield (60.9%; 19th trunk lichen frequency). Slightly more sites (33) had trunk lichens than canopy lichens (31). All of the trees at Oodla Wirra, Terowie, Hawker, and Port Augusta had neither trunk nor canopy lichens.

Figure 5.2 summarises the four canopy lichen-trunk lichen classes for all trees at all study sites. The highest number of trees (274, 44.1% of all trees) had neither canopy nor trunk lichens, while 208 trees (33.5%) had both canopy and trunk lichens. The most interesting classes are of those trees with lichens in the canopy but not on the trunk, and vice versa. Ninety-two individuals have canopy lichens but no trunk lichens (14.8% of all trees) and 47 trees have trunk lichens but no canopy lichens (7.6% of all trees).

Table 5.5 Canopy and trunk lichen occurrence ranked by percentage of trees with lichens growing on their trunks.

Site	Trees sampled	% trees with trunk lichens	% trees with canopy lichens	% trees with trunk and canopy lichens
Gumeracha	23	69.6	78.3	69.6
Freeling	20	69.6	65.2	52.2
Lobethal	26	65.2	87.0	65.2
Springton	20	65.2	60.9	60.9
Meadows	15	52.2	52.2	47.8
Hallett	15	52.2	43.5	43.5
Stirling	21	47.8	69.6	43.5
Lyndoch	17	43.5	39.1	39.1
Mount Barker	19	39.1	60.9	34.8
Jamestown	18	39.1	47.8	34.8
Williamstown	15	39.1	43.5	34.8
Tarlee	16	39.1	30.4	30.4
Pt. Wakefield	20	39.1	8.7	8.7
Mylor	24	34.8	91.3	30.4
Clare	15	34.8	43.5	34.8
Robertstown	15	34.8	39.1	26.1
Angaston	15	30.4	52.2	30.4
Two Wells	15	30.4	39.1	30.4
Macclesfield	15	26.1	60.9	26.1
Rhynie	15	26.1	30.4	26.1
Spalding	16	26.1	26.1	26.1
Burra	15	21.7	34.8	21.7
Eudunda	16	21.7	26.1	8.7
Crystal Brook	15	21.7	21.7	21.7
Truro	15	21.7	21.7	13.0
Orroroo	15	21.7	17.4	13.0
Peterborough	15	21.7	0.0	0.0
Auburn	15	17.4	47.8	8.7
Gawler	15	13.0	26.1	8.7
Snowtown	16	13.0	4.3	4.3
Bridgewater	17	8.7	34.8	4.3
Port Germein	18	8.7	0.0	0.0
Carrieton	15	4.3	0.0	0.0
Oodla Wirra	15	0.0	0.0	0.0
Terowie	15	0.0	0.0	0.0
Hawker	15	0.0	0.0	0.0
Port Augusta	15	0.0	0.0	0.0

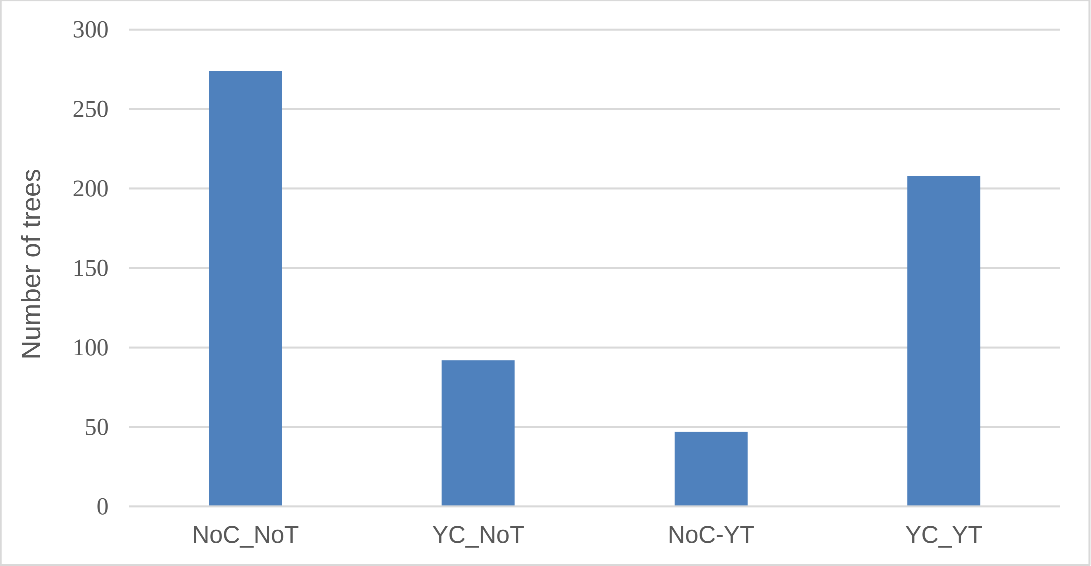


Fig. 5.2 Presence and absence of lichens on trunks and in canopies.
Key: NoC-NoT: No lichens in canopy or on trunk; YC-NoT: Lichens in the canopy, no lichens on trunk; NoC-YT: No lichens in the canopy, lichens on the trunk; YC-YT: Lichens in the canopy and on trunk.

Trees which only have canopy lichens were mostly found at the medium rainfall sites (Table 5.1). Eleven of the 15 sites had trees with just canopy lichens at the intermediate rainfall sites compared to only one of 10 and four of 11 at the low and high rainfall sites respectively. This suggests that canopy lichens grow once humidity levels increase above a threshold that is lower than that required for many trees to have trunk lichens. Given the earlier comments about the relatively unimpeded pathway of solar radiation to tree trunks and low wind resistance at study sites in the arid and semi-arid parts of the area studied, the preferential occurrence of trees which only have canopy lichens at medium rainfall sites could be explained in terms of the slightly reduced levels of solar radiation in the tree canopies and greater frictional resistance to wind.

It is more difficult to explain the distribution of trees which only have trunk lichens than those which only have canopy lichens as there is no clear pattern in the numbers of study sites in each rainfall class with trunk lichen only trees; five of 11, eight of 15 and six of 10 for the high, medium and low rainfall sites respectively.

Only for one species, *Platanus orientalis*, do all the specimens sampled fall into one of these two classes, the canopy lichens-no trunk lichens class. This can be explained in terms of the exfoliating bark found on all these trees, though with only four samples there remains the possibility of other specimens having both trunk and canopy lichens. Other tree species where a relatively high numbers of specimens sampled fell into one of these two categories were *Brachychiton populneus* and *Casuarina glauca* (3 of 7 and 4 of 8 trees in the trunk only lichen class respectively) and *Ulmus procera* (8 of 16 individuals in the canopy only lichen class).

An analysis of lichens in the canopies and the trunks of trees for genera or species where at least ten individual trees had been sampled was conducted. This excluded *Eucalyptus* as a genus because of the large number of species, many growth forms and a significant number of unidentified species (Section 3.3). In all, 16 classes (genera or species) were analysed. Only *Eucalyptus porosa* falls entirely into one of the four classes — the no canopy-no trunk lichens class – in Figure 5.2. By way of contrast, no individuals of *Quercus* sp. occurred in the no canopy-no trunk lichens class. At the other end of spectrum, 90.3% of *Fraxinus* sp. trees had lichens in both their canopies or trunks. Again, by way of contrast, no individuals of *Schinus molle* or *E. camaldulensis* had lichens growing on either their trunks and canopies. Trees with lichens growing on their trunks, in the canopies and on both their trunks and canopies are highly correlated (Table 5.6).

Table 5.6 Pearson correlation coefficients for associations between trees with lichens on trunks, in canopies, and in both trunks and canopies at all study sites, n = 37.

		In canopy	On trunk/in canopy
On trunk	R^2	.785**	.943**
	Sig. (2-tailed)	.000	.000
In canopy	R^2		.848**
	Sig. (2-tailed)		.000

** Significant difference at *p* = 0.01

It is relatively straightforward to explain the growth of trees with lichens on their trunks and in their canopies, and trees with no lichens at all. Trees with trunk and canopy lichens were mainly found in the wetter, cooler parts of the ecotone while those without lichens were found in the drier and hotter northern areas. For example, 66.2% of all trees at high rainfall sites had canopy lichens compared to only 6.9% at low rainfall sites. In terms of trees that had neither trunk nor canopy lichens, 87.7% of trees at the low rainfall sites fell into this category, while the percentage fell to 54.1% at the high rainfall sites. These trends are supported by the intermediate distribution of trees with canopy lichens, but no trunks lichens along the ecotone researched. There are, however, exceptions to this general rule, i.e. trees which generally do not have lichens because of their bark properties such a low pH or exfoliating bark. For example, a specimen of *Indigofera australis* (tree: BRI09) which has no canopy or trunk lichens at Bridgewater, a high rainfall site. The lack of lichens in this case may be due to the very low bark pH of 3.2. There are also trees at low rainfall sites with canopy and trunk lichens. For example, ROB10 and ROB11, specimens of *E. torquata* and *Melia azedarach* respectively, at Robertstown. Other specimens of these two species do not always have canopy and trunk lichens, meaning the likely explanation is due to following hydroclimatic conditions. While this is a low rainfall site, its low-lying location means that water accumulates after seasonal runoff from surrounding higher ground and this may lead to greater amounts of lichen growth than might be anticipated.

The straightforward explanation for these trends is, bark properties aside, that:

- in addition to the higher frequency of trunk lichen in the cooler, high rainfall areas, tree crowns are often denser and tree densities are slightly higher leading to some overlapping canopies, which will lead to a more humid canopy microclimate;
- in addition to the lower frequency of trunk lichen in the hotter, low rainfall areas, tree crowns are very sparse, and trees are often more widely spaced than in the high rainfall areas. Both of these factors create an arid canopy microclimate.

5.3 Regional microclimate

It is important to understand the broad climate patterns in the study area before attempting an analysis of lichen distribution and regional microclimate. The overall patterns of precipitation, temperature and evaporation are similar in that they have strong N-S and E-W gradients. The descriptions of the temperature, rainfall and evaporation patterns below are based on 1985 and 2015 SILO data records (Section 3.3).

Mean annual precipitation generally decreases northwards (Figure 3.2, Figure 5.1). It is markedly higher in the Adelaide Hills due to the elevated topography (approximately 300 m.a.s.l. to Mount Lofty at 727 m.a.s.l.) and well-dissected topography. A decline in precipitation eastward is evident in the Mid North and Southern Flinders Ranges with the exception of a high rainfall zone along the elevated south-central spine of the region, which in the Mid North is known as the Clare and Gilbert Valleys and further north becomes the Southern Flinders Ranges themselves. Mean annual temperatures increase northwards due to loss of elevation and the latitudinal gradients. Summer and winter temperatures have similar spatial patterns to mean annual temperatures, with the exception of winter temperatures, which are markedly colder in the interior (east of the study area) than along the coast due to influence of continentality. Mean, summer and winter annual evaporation rates also have strong gradients that parallel those of temperature. Even within the sites sampled in the Adelaide Hills there is a SE-NW gradient with the mean annual evaporation rates at Stirling being 1124mm, while at Lyndoch in the north west it is 1373mm (Figure 5.4). In along the central transect through the Mid North and Southern Flinders Ranges mean annual evaporation rates range from 1465mm at Gawler to 2274mm at Hawker. There is a strong EW gradient, with high values along the Gulf St. Vincent and Spencer Gulf coasts (1507mm in the south to 2031mm in the north) to much lower values in the interior that range from 1227mm at Robertstown to 1663mm at Oodla Wirra that is related to lower inland temperatures during winter months than those along the coast.

Kendall's Tau (τ) was used to test for associations between the climate parameters and lichen frequency and cover. The main focus was on associations between the frequency of *X. parietina* and climate parameters. However, while frequency is a primary lichen variable in this research, proportional cover was also calculated as it may reveal different information about lichen growth and distribution than lichen frequency. A summary of the correlations between *X. parietina* frequency and cover with precipitation, temperature and evaporation data are given in Tables 5.7, and 5.9 respectively.

Table 5.7 Summary of Kendall's τ correlation coefficients between *X. parietina* frequency and climate parameters.

Aspect		Mean annual rainfall	Mean sum. rainfall	Mean win. rainfall	Mean annual temp.	Mean win. min temp.	Mean sum. max temp.	Mean annual eva.	Mean win. eva.	Mean sum. eva.
All sites (n= 37)	τ	.318**	.175	.307**	-.367**	-.234**	-.374**	-.344**	-.325**	-.372**
	Sig.	.007	.137	.009	.002	.049	.002	.003	.005	.002
Only sites with *X. parietina* (n= 29)	τ	.126	.011	.157	-.285	-.223	-.247	-.213	-.179	-.258
	Sig.	.514	.954	.415	.134	.246	.197	.106	.176	.051
Only sites with *X. parietina* on S aspects (n= 28)	τ	.214	-.120	.240	-.352*	-.096	-.347*	-.223	191	-.281*
	Sig.	.113	.373	.075	.010	.487	.011	.097	.155	.036

** significant at the 0.01 level (2-tailed test), * significant at the 0.05 level (2-tailed). n: number of sites calculated

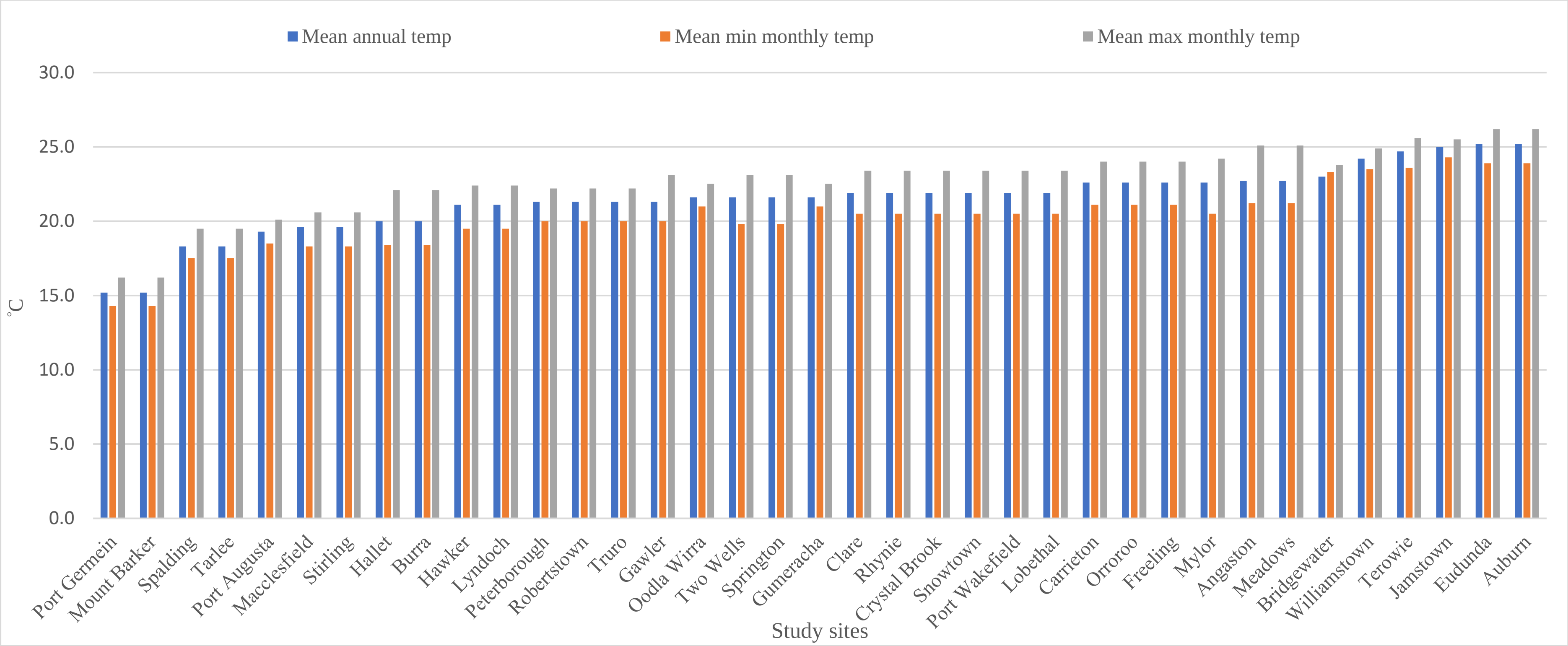


Fig. 5.3 Mean annual, winter minimum and summer maximum temperature data (1985-2015), ranked by mean annual temperature. Source: Calculated from SILO data downloaded in 2018.

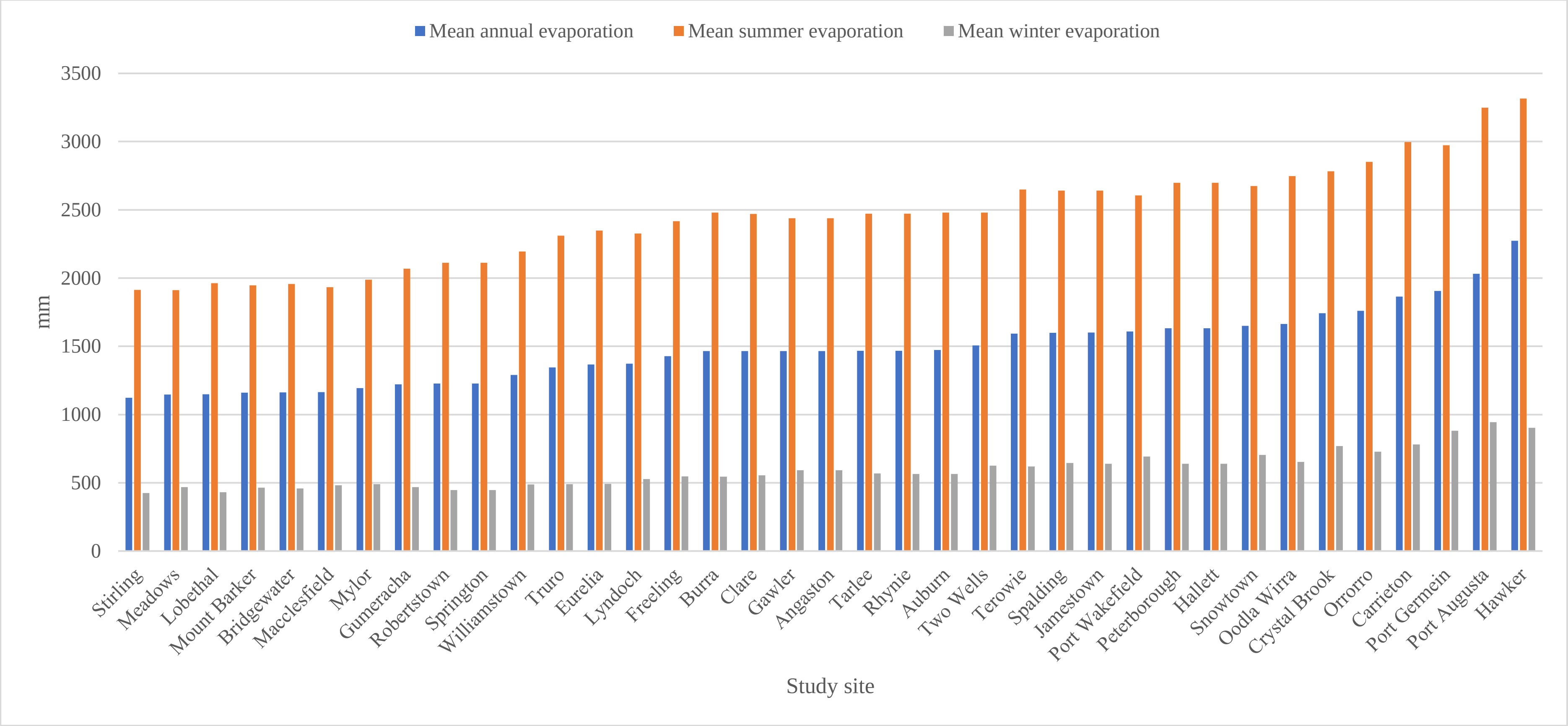


Fig. 5.4 Mean annual, summer and winter evaporation rates for each study site, ranked by mean annual evaporation. Source: Calculated from SILO data downloaded in 2018.

Ecological theory suggests that increasing precipitation and decreasing temperature and evaporation should be reflected in an increase in lichen frequency (M.R.D. Seaward, 1977). However, the fit with ecological theory was at the best moderate in that all correlation coefficients are low, ranging from $\tau = 0.011$ to $\tau = -0.374$. Though as expected from theory, all associations with precipitation are positive and those with temperature and evaporation negative. The main issue is that many of the τ values in Table 5.7 are not significant at $p < 0.05$. An exception to this is that that eight of the nine τ values for all sites (Table 5.7, 1st row) were highly significant. This enables the trend apparent at all sites in which frequency increases as mean winter and annual precipitation increase, and mean winter, summer and annual temperature and evaporation rates decrease, to be used to make inferences about regional climate-lichen relationships. Comparing these significant correlations across geographical scales, they support the observations made about lichen growth on trunks in Section 5.2.1, and elements of the logic used to explain trunk distributions in that section may apply at the regional scale as well — in particular those related to temperature and evaporation.

However, when τ values were calculated for (i) the 29 sites where *X. parietina* was sampled, and (ii) the 28 sites where *X. parietina* occurs on the south aspects of trunks (Table 5.7, 2nd and 3rd rows), the correlations were lower than for all sites and only three were significant. These were mean annual temperature ($\tau = -0.352$, significant at $p = 0.05$), mean summer maximum temperature ($\tau = -0.347$, significant at $p = 0.05$) and mean summer evaporation ($\tau = -0.281$, significant at $p = 0.05$) for *X. parietina* at the 28 sites where it was found on the south aspects of trunks. No significant τ values were revealed for either precipitation or temperature parameters for the 29 sites where *X. parietina* was sampled, nor for precipitation at the other 28 sites where *X. parietina* occurs on the south aspects of trunks.

These observations broadly support the argument for lichen growth and regional climate in Europe put forward by Ellis, Coppins, and Dawson (2007). However, the generally low correlation coefficients (of which over half are not significant) suggest that further research on lichen occurrence along dry sub-humid to arid ecotones is required before it can be argued that the theoretical ecological underpinnings presented by Seward (1977) can be applied without modification in these climate zones.

Kendall's Tau (τ) was also used to investigate relationships between climate parameters and *X. parietina* cover (Table 5.8). Generally, there were significant negative correlations between cover and temperature, though only those between mean annual temperatures (τ = -0.251) and mean summer maximum temperatures (τ = -0.284) were significant (Table 5.8, first row). As anticipated there were positive correlations with precipitation, though only those between mean annual rainfall (τ = 0.318) and mean winter rainfall (τ = 0.292) were significant. However, the role of evaporation in influencing lichen distribution is very clear from these results, and it interesting to note that all the correlations between lichen cover and mean annual, winter and summer evaporation were significant for all three samples. The correlation coefficients for all sites (Table 5.9, first row, were higher than for temperature or rainfall at

τ = -.412, -.439 and -.433 ($p = 0.01$) respectively for annual, winter and summer evaporation. When the samples for all sites with *X. parietina* and *X. parietina* on the south sides are examined, significant correlations between all evaporation parameters and *X. parietina* were also found to be significant, whereas none of the correlations between *X. parietina* and rainfall or temperature were. If Tables 5.7 and 5.8 are considered together, the relationships between climate and *X. parietina* frequency and cover have strong similarities and are mutually reinforcing.

Table 5.8 Summary of Kendall's tau correlation coefficients between *X. parietina* cover and climate parameters.

Aspect		Mean annual rainfall	Mean sum. rainfall	Mean win. rainfall	Mean annual temp.	Mean win. min temp.	Mean sum. max temp.	Mean annual eva.	Mean win. eva.	Mean sum. eva.
All sites (n= 37)	τ	.318**	.167	.292**	-.251*	-.153	-.284*	-.412**	-.439**	-.433**
	Sig.	.006	.155	.012	.034	.196	.015	.000	.000	.000
Only sites with *X. parietina* (n= 29)	τ	.161	.052	.146	-.249	-.193	-.248	-.337*	-.401**	-.327*
	Sig.	.222	.693	.268	.066	.155	.067	.011	.002	.013
Only sites with *X. parietina* on south aspects (n= 28)	τ	.181	.093	.191	-.149	-.027	-.201	-.287*	-.356**	-.277*
	Sig.	.179	.489	.155	.275	.843	.138	.033	.008	.040

** significant at the 0.01 level (2-tailed test), * significant at the 0.05 level (2-tailed). n: number of sites calculated

It is possible to infer that higher precipitation and lower temperatures and evaporation rates leads to increased frequencies of *X. parietina*. But this inference can only be made for the sites where that lichen was found growing. It is important to note that all of the study sites apart from one — Bridgewater – where *X. parietina* was not encountered while sampling were the eight most northerly study sites. These are typically arid with low rainfall and high evaporation rates. Mean annual and seasonal temperatures do not show a clear pattern. This enables precipitation, temperature and evaporation thresholds below which *X. parietina* was not found on the trees sampled to be identified (Table 5.9). In this table the limiting values or thresholds for precipitation below which *X. parietina* did not occur and the evaporation thresholds above which the lichen was not found to be identified. These thresholds need to be treated with some caution, as they are (i) only based on the study sites and trees sampled, and (ii) based on 1985-2015 precipitation and evaporation data. In addition, *X. parietina* was found on trees at some study sites where the precipitation was less than the limiting value derived from the highest value for the eight northern arid stations, or where the evaporation rates were less than the limiting value derived from the eight northern stations. Therefore, in Table 5.8 the limiting values or thresholds for *X. parietina* are shown as ranges, along with the ranges of the parameters for all study sites (in italics).

Table 5.9 Ranges of limiting values or thresholds for precipitation and evaporation parameters for *X. parietina* growth at the northern, arid end of the climatic gradient in the study area.

Aspect	Mean annual rainfall (mm)	Mean win. rainfall (mm)	Mean sum. rainfall (mm)	Mean annual Eo (mm)	Mean win. Eo (mm)	Mean sum. Eo (mm)
Limiting value range	<338.6 to 315.8	<117.2 to 104.5	<79.7 to 46.0	>1593.1 to 1742.3	>618.8 to 768.4	>2648.3 to 2782.3
Range of values (all study sites)	*252.8 to 995.4*	*69.9 to 403.8*	*52.8 to 104.2*	*1123.9 to 2273.6*	*425.6 to 943.6*	*1912.6 to 3325.1*

5.3.1 Maritime influences

Two large marine embayments of the Great Australian Bight — the Spencer Gulf and Gulf St. Vincent – lie to the west of the study area. Potential maritime influences on lichen frequency arise through phenomena such as storms, which are related to depressions tracking across southern Australia from the south-west Indian Ocean, and salt deposition. These were explored by correlating the shortest vector distance between each study site and the nearest element of coastline to *X. parietina* frequency and cover. No significant relationships were found (τ = +0.165, frequency; τ = +0.129 cover). While maritime influences probably exist, these correlations suggest that they either have little impact on *X. parietina* frequency and cover or be could accounted for in regional microclimate trends or, in the case of salt deposition, in the bark pH (Section 4.6.1).

5.3.2 Discussion

The relationships between regional microclimate and lichen frequency and cover are in line with those of Armstrong and Bradwell (2011) and Nash (2008), who found that differences in lichen abundance, diversity and growth rates can be explained in terms of spatial variability in climate and hydrometeorological parameters at a landscape scale. Armstrong and Bradwell (2008) noted the key role of moisture availability, which itself mirrors earlier work in temperate biomes by Paterson *et al.* (1983). Importantly in the context of this research, the latter authors pointed out a more complex relationship between lichens and a range of climate variables that included precipitation and temperature parameters. Temperature itself was investigated as a controlling variable on lichen distribution by Ozturk *et al.* (2010).

While the regional climate-lichen relationships found in the studies referenced above are intuitive, two things are striking:

- there has been no empirical research examining lichen-climate relationships along environmental gradients that extend from sub-humid climates to the fringes of desert (in this research from the wettest parts of the Adelaide Hills to the arid land townships such as Hawker, Oodla Wirra and Port Augusta); and
- generally, there is a paucity of empirical studies on lichen-climate relationships at this scale.

Maybe lichenologists assume these relationships exist. This may be premature because this research indicates our understanding of these landscape-scale phenomena are far from complete. More studies are required in locations in under researched climate zones like the arid and semi-arid zones covered in this study. This is particularly important if the use of lichens as indicators of climate change (Section 2.6) is to be robustly applied.

A new element of this regional climate analysis was to incorporate evaporation rates. To the author's knowledge there has only been one published study on evaporation and epiphytic lichens. Neilker and Orvig (1958) measured evaporation and evapotranspiration through the growing season in Labrador-Ungava, Canada and found that where there was lichen cover, evapotranspiration was approximately a third of the theoretical estimate of evaporation. They concluded lichen cover affects the evapotranspiration and as lichens grow evapotranspiration rates increase, as would be the case for higher plants.

The role of evaporation and evapotranspiration in lichen growth is clearly an area that would benefit from further research. One of the key issues to be tackled is that of scale, as is the case in this research, where our understanding of corticolous lichen-climate relationships crosses geographical scales — ranging from the trunk-scale to the regional climate scale in lacking. An argument that is supported by Giordani and Incerti (2008) who encouraged research into the interplay of variables that influence lichen growth at different scales to improve understanding of lichen distribution, diversity and growth.

On the basis of the research findings presented in this chapter, a simple water balance model approach (Figure 5.5) is suggested. Precipitation is the parameter that is measured at climate stations, and therefore this is the parameter whose relationship with lichen occurrence and frequency has been most frequently tested. However, lichens importantly obtain moisture from condensation of water vapour onto them, direct precipitation from driving rain, and through stem flow. The latter being the hydrological process that directs water along trunks. In Figure 5.6, damp areas caused by stem flow on the lower trunk of a tree sampled are clear, as is the preferential growth of small lichens in these areas of stem flow. Direct precipitation, condensation and stem flow are the inputs into the proposed water balance model that might replace precipitation. The outputs are continued stem flow down the trunk and evapotranspiration. None of these three processes operate at the regional scale, the scale at which precipitation records exist.

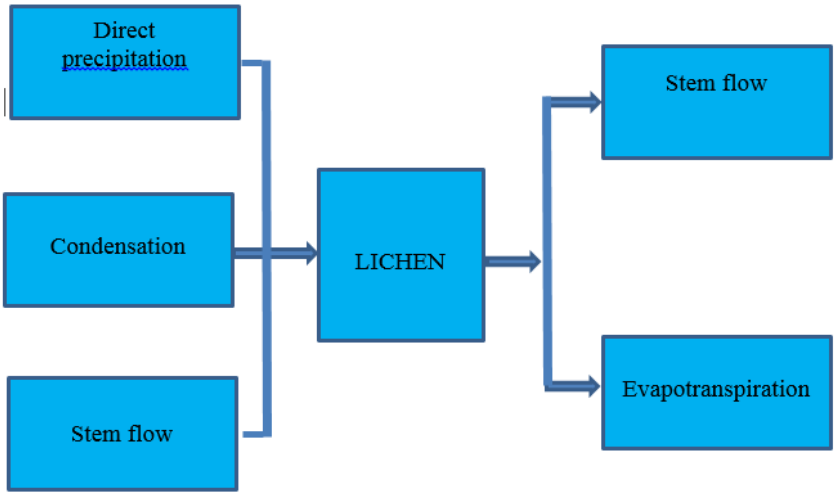


Fig. 5.5 A simple water balance model to understand lichen-moisture relationships.

Using this model to guide measurements on individual tree trunks would enable moisture availability to be measured and related to lichen frequency and cover. If measurements could be made for individual lichens over very long time periods, responses by individual lichens could be determined.

Fig. 5.6 Stem flow and lichen occurrence, Gumeracha (tree: GUM8). The darker areas of the trunk are lines of stemflow. The finger is pointing too small areas of lichen (green) in the rivulets of stemflow.

5.4 Summary

In terms of tree microclimate, there are significant differences in lichen cover between the N, E, S and W aspects for all tree samples, for *X. parietina*, and for *X. parietina* growing on *Fraxinus* sp. trees, but not for *C. holocarpa.*

Post-hoc Dunn's tests showed that all significantly different pairs of aspects in terms of lichen growth included the south aspect. This result fits with previous studies and stresses the importance of incident solar radiation and the relative humidity of the trunk in relation to lichen growth.

Canopy lichens were recorded on many trees sampled. The occurrence of trunk and canopy lichens at the 37 sites is significantly different. Nonetheless, trees with more lichens growing on their trunks are more likely to have lichens growing in their canopies, and on both trunks and canopies as well.

In terms of regional-scale climate-lichen relationships, *X. parietina* frequency increases with:

- increasing annual, summer and winter precipitation;
- decreasing annual, summer and winter temperatures in general; and
- decreasing annual, summer and winter evaporation.

These results are intuitive and fit existing ecological theory, and are indicative of *X. parietina* — the most commonly occurring lichen in the study area – preferring moister and cooler climates. A weak positive correlation between *X. parietina* frequency and summer rainfall for all sites indicates that trees in locations with higher summer rainfall may have greater lichen frequencies. This is similar to the evidence put forward by Ellis, Coppins, Dawson*, et al.* (2007) from Europe. Ranges of values for rainfall and evaporation parameters were derived which equate the probable limiting thresholds for *X. parietina* growth at the arid, northern end of the climatic gradient studied.

The results of empirical research on the relationships between lichen frequency and cover and microclimate, and regional climate, are presented in this chapter. The results have been discussed in the context of research done in other biomes, and future research into the climate controls on lichens. However, it must be borne in mind that some of these trends are not statistically significant and require further research to confirm their veracity.

CHAPTER SIX

THREATS TO EPIPHYTIC LICHENS, THEIR CONSERVATION STATUS AND POTENTIAL CONSERVATION STRATEGIES

6.1 Introduction

This chapter addresses the conservation status of lichen generally (Section 6.2); expands on the previous discussion of threats to lichens and doing so makes specific reference to South Australia (Section 6.3), and then reviews strategies for lichen conservation (Section 6.4) before drawing some conclusions which is hoped have relevance to South Australia in Section 6.5.

6.2 Conservation status of lichens

There are 13,500 to 17,000 lichen species according to Chapman (2009) (Table 6.1). Other estimates in this range are Nash (2008) and (International Union for Conservation of Nature, 2017), while earlier estimates of around 20,000 (Hale, 1974; Filson & Rogers, 1979) are not that different given our lack of knowledge (Section 1.1).

Table 6.1 Lichen species estimates globally and in Australia.

Geographical Region	Descriptor	Estimate
World	Described and accepted, maximum and minimum	10,000-20,000
	Described and accepted, latest quoted value	17,000
	Estimate	25,000
	Threatened (as percentage of World described and accepted, see 1st row of this table)	2 (0.1%)
Australia	Described and accepted	3,495
	Estimate	Approx. 4,500
	Endemic	34%
	Threatened	0

Sources: IUCN (2004, 2017), Deacon (2005), McCarthy (2009)

The International Union for Conservation of Nature (IUCN) lists only eight lichen species on the red list (Table 6.2).

Table 6.2 Lichen species on the IUCN red list.

Name of lichen species	Occurrence	Extinct	Extinct in the wild	Critically endangered	Endangered	Vulnerable	Threatened
Anzia centrifuga	Portugal (Madeira)					*	
Buellia asterella	Germany; Norway			*			
Cetradonia linearis	United States (Georgia, the Carolinas and Tennessee)					*	
Cladonia perforata	United States (Florida)				*		
Erioderma pedicellatum	Canada (Newfoundland, Nova Scotia); USA (Alaska)			*			
Gymnoderma insulare	Japan and Taiwan				*		
Leptogium rivulare	Belarus; Canada (Manitoba, Ontario); France (mainland); Lithuania; Russian Federation; Sweden; United States (Illinois and Vermont, possibly extinct in Wisconsin)						*
Ramalina erosa	Portugal (Madeira)				*		

The standard IUCN categories used in Table 6.2 are defined as follows. Extinct refers to taxa with no existing individuals in the wild or in captivity. Extinct in the wild refers to taxa known only to occur in captivity or in populations outside their natural range. Critically endangered refers to taxa that are at extreme risk of extinction in the wild. Endangered are taxa are at risk of extinction. Vulnerable are taxa that are at high risk of extinction in the wild, and threatened taxa are likely to become endangered in the foreseeable future.

6.2.1 Lichens in Australia

Australia is one of 17 megadiverse nations in the world (Government of Australia, 2016). Despite this, cryptograms including lichens have received relatively little attention (Pouliot & May, 2010). Morley and Gibson (2005), who worked on the conservation of epiphytic lichens in Victorian cool temperate rainforests, argued that it was important to conserve and protect a range of forest successional stages as each stage may hold one or more rare lichen species.

Tasmania brings into focus many issues related to the protection and conservation of lichens in Australia. The state has around 1000 lichen species, and conservation efforts have been built around threats to natural areas and World Heritage sites from forestry and hydroelectricity development. Lichenology is far more advanced in this state than any other in Australia. A number of researchers have studied lichen conservation in different Tasmanian ecosystems, e.g., Jarman *et al.* (1984) and Jarman *et al.* (1994) in cool temperate rainforests; Kirkpatrick *et al.* (1988) in wet eucalyptus forests;

F. Duncan and Brown (1985) in dry sclerophyll vegetation; Kirkpatrick and Harris (1995) examined coastal vegetation; and Jarman *et al.* (1988) who researched buttongrass moorland. Other scientists have looked at the conservation of a single species: Potts (1989) researched *Eucalyptus cordata;* Peterson (1990) focused on *Lagarostrobos* franklinii*,* and Brown (1988) examined *Anthrotaxis selaginoides.*

Four lichens are listed as threatened species according to the *Threatened Species Protection Act 1995* in Tasmania (Kantvilas (2000). These are:

- *Xanthoparmelina vicaria* Elix & J. Johnst. is endemic to Tasmania and part of a rare population on the island;
- *Punctelia subflava* (Taylor) Elix & J. Johnst., which is listed as nearly extinct as none have been collected in Tasmania since 1839, but is still found on the Australia mainland in disturbed and fragmented coastal swamp forests;
- *Hypotrachyna laevigata* (Sm.) Hale., which is listed as vulnerable in Tasmania, though it is found widely in the Northern Hemisphere*;* and
- *Parmotrema crinitum* (Ach.) M. Choisy., which is listed as rare since it has only a very small population in lowland swamp forest.

In addition to these, he noted that three more species were likely to be added to the red list for Tasmania in the future: *Xanthorpamelia jarmaniae* Elix & Kantvilas, *X. willisii* (Kurok. & Filson) Elix & J. Johnst. and *X. molliuscula* (Ach.) Hale.

I have analysed the information for threatened and vulnerable species listed for South Australia in the Atlas for Living Australia and Schedules 7, 8 and 9 of the South Australia National Parks and Wildlife Act (Government of South Australia, 2017) which list endangered, vulnerable and rare species for South Australia respectively. No lichens appear on any of the lists, or even on the more numerous South Australia National Parks and Wildlife Act schedules. The author believes the fact that no lichens are listed in these documents reaffirms supports the case made earlier in this thesis that lichens are not foremost in the minds of many scientists when it comes to conservation issues, let alone recognised by a wider public. However, the recently published long term conservation strategy for South Australia—*No Species Loss (A Nature Conservation Strategy for South Australia 2007-2017)* (Department for Environment and Heritage, 2017) – has provision for lichen conservation. On the one hand this leaves the issue of whether there are lichens present in South Australia that are threatened and possibly in need of a conservation listing. On the other, it does not mean lichens are not under threat in the state. Definitive statements cannot be made until more research is carried out.

6.3 Threats

Threats to lichens were reviewed in Section 2.6 and encompass a number of processes that they share with many other organisms, from both the plant and animal kingdoms. This section details with the principal threats to epiphytic lichens globally and highlights the potential implications for South Australia. The list of threats identified by Brown *et al.* (1994) in Tasmania is the most extensive work that focuses on Australia.

6.3.1 Habitat loss and fragmentation

Habitat loss is one of the most important processes threatening organisms across the globe. This is most usually due to human activities associated with agriculture (e.g., clearance and fragmentation of natural vegetation, land degradation, and changes in the microclimate) and urban and infrastructure development (e.g., land clearance, fragmentation of natural vegetation, construction of impervious surfaces, and flooding vegetated areas after dam construction). Though there are also natural disturbances that destroy habitat such as landslides, mudflows, flooding and severe droughts.

Specifically, with regard to epiphytic lichens, the major causes of habitat loss relate to processes impacting forests and woodlands, e.g., tree clearance for agriculture and urban and infrastructure development, exploitation of forest resources (clear felling, plantation forestry) and flooding forests and woodlands, changes in forest fire regimes (Thor, 1998), and changes to the microclimate in remaining forest patches.

Natural forests and woodlands

Timber harvesting from, and land use conversion of, natural forests continues apace to the present day, with four areas suffering the biggest losses at the present time: humid tropical forests in South America, Central Africa and Southeast Asia and boreal forests in Russia. They account for up to 60% of the world’s remaining forests (Scotland & Ludwig, 2002). It is estimated that these regions have more lichens than other regions but large tracts were lost during the 1990s (Scotland & Ludwig, 2002). Specific examples include Grube (2010), who recorded the loss of epiphytic foliicolous lichen due to logging, and

Wolseley and Aguirre-Hudson (1997), who found that lichens were being lost in northern Thailand due to the high rates of forest destruction.

Much native woodland in South Australia was cleared as the agriculture base of the colony expanded outward from Adelaide, settlement occurred in parallel. This was also the case in other colonies (now states) of Australia (Benson, 1991). In South Australia early clearance occurred in the nineteenth century in the Adelaide Hills (from the late 1830s), the Mid North and Southern Flinders Ranges (from the 1840s onwards: (Meinig, 1961; Meining, 1962; Williams, 1976; Heathcote, 2004; Nidumolu *et al.*, 2012)) and in the south east around Mount Gambier around the same time. In the early to mid-twentieth century woodland in the Murray Mallee, Eyre Peninsula and Kangaroo Island was cleared. Although I have found no specific records to the loss or reduction in lichen flora during these phases of bush and woodland clearance, there is little doubt it did occur. However, as Table 4.2 shows, lichens tend to be more common on trees that are not native to the study area. Bush clearance slowed down considerably in the 1980s, however by that time most of the natural woody vegetation had been cleared in the central and northern parts of the study area, and it is now regulated under the Native Vegetation Act 1991 (SA) (Government of South Australia, 2016), which allows certain forms of clearance under licence (DEWNR, n.d.).

Expansion of agricultural landscapes

The expansion of agricultural landscapes, which has been a constant theme in global land cover change over the last two millennia, and particularly in the last 70 years, and had accounted for the destruction of much woody vegetation and has led to structural landscape changes. For example, many wooded meadows and pastures have disappeared in Sweden with the consequent loss of lichens. However, Thor (1998) has noted that epiphytic lichen flora can persist if trees are conserved in agriculturally-dominated landscape. Sometimes it is not just forest clearance that is the threat. Other co-factors come into play. In Italy, overexploitation of oak forests tied to the co-factor of a locust invasion in 2010, led to a reduction in epiphytic lichen habitat. Nascimbene and Marini (2010) concluded that the commercial use of oak forest or its clearance for arable lands is the main threat to many lichen species in the country. As shown in the section above, bush clearance in the Adelaide Hills, Mid North and Southern Flinders ranges has mainly been undertaken to clear land for agriculture.

Expanding plantation forestry landscapes

Thor (1998) considered the expansion of commercial forestry to be a serious threat to lichens in Scandinavia because 9.4 million hectares of forest were lost due to the clearance of natural forests and their replacement by plantations of exotic trees during the 1990s. This situation is commonplace in many countries from regions as diverse as the sub-tropical southern USA; the cool temperate rainforests of Chile (Echeverria *et al.*, 2006) and New Zealand (Quinn *et al.*, 1997); and in the high Andes (Ross *et al.*, 2017). Red-listed lichens (from the Swedish regional red list) account for a significant proportion (67%) of all lichens in Swedish forests. In managed forests 95% of lichens were red-listed (Gamlin, 1988). Clear-felling in these forests mitigates against the temporal continuity of lichen habitat, which is particularly important as trees older than 100 years have more red-listed lichens than younger trees.

The majority of plantation forest landscapes in South Australia are in the south east of the state, and therefore are not directly relevant to the study area. However, the Bundaleer and Wirrabarra Forests (established in 1875 and 1877 respectively) are plantation forests in the Southern Flinders Ranges to which these arguments may apply. They were not sampled in this research as they did not fit either the research questions being asked nor the sampling plan.

Disease and invasive species

Plant diseases that affect host trees may be detrimental to epiphytic lichens. *Phytopthora cinnamomi* affects many trees and shrubs in the *Banksia, Hakea,* and *Agastachy* genera and may reduce abundance of host species for some epiphytic lichens. Invasion by introduced flora may also contribute to changing light and moisture conditions that might also affect lichen habitats (Podger, Palzer*, et al.*, 1990).

Fire

Fire can be a serious threat to lichens. When whole trees are burnt during intense canopy fires, the epiphytic lichens — in the canopy or on the trunk — are destroyed and habitat for the establishment of new species is lost. Even in lower temperature ground fires, many trunks get charred and this can kill the lichens on the lower trunk. Those lichens higher up the trunk and in the canopy are unaffected (though there may be smoke damage but to the author's knowledge this has not been researched). As the trees recover, the bark substrate regenerates and lichens have the opportunity to re-establish. Brown *et al.* (1994) have argued that fire can also remove many other important lichen and bryophyte habitats such as dead wood, peat in rock crevices and old or diseased trees in mixed-aged forests. They also noted that fires create new but unsuitable substrates for lichens such as charcoal, and scorched soil and rock.

Fire is an essential natural regeneration process in many types of forest and woodland. For example, Brown *et al.* (1994) noted its role in fire-prone sclerophyll heathlands and woodlands in Tasmania. Many plant species in such ecosystems thrive in the immediate post-fire conditions, but epiphytic lichens do not. This is because they have to establish after vascular tree growth and new arboreal habitats have to be created (Cremer & Mount, 1965; D. Duncan & Dalton, 1982).

The paradox is that fire can be used as an ecosystem management tool in many countries — in particular in Australia — to reduce fuel loads, facilitate forest regeneration and to maintain faunal habitats. The condition of the vascular flora is considered in the management of the fire regime, but the particular requirements, characteristics, and vulnerability of non-vascular plants are not. As lichens and bryophytes are dependent on the vascular plant habitats there is a lag in the post-fire recovery of non-vascular and vascular plants. No controls are in place to ensure that non-vascular species can recover before the next fire. Kantvilas and Jarman (1988) showed that lichens can decrease dramatically in some Tasmanian buttongrass moorland communities as the result of current fire management regimes. Garrido-Benavent *et al.* (2015) argued that the interaction of agriculture and recurrent fires influence lichen diversity in Mediterranean areas. They examined fire regimes in the context of epiphytic lichens on *Quercus ilex* (in Spain and found that trees that were affected by fire had lower lichen diversity than trees in agricultural areas).

The points made about fires in this section apply to native and, to a lesser extent, planted trees in the study area. Two types of fires occur in the region. Controlled burns which are normally relatively cool, ground fires which may damage the bark on the lower trunks of some trees and therefore will destroy some corticolous lichens. The second types are wildfires, which if the climate conditions are favourable may develop into hot burns that destroy entire trees over large areas. Two very large wildfires occurred in the study area during the period of my PhD. The first, the Bangor fire in the Southern Flinders Ranges, burnt over 23,000ha of native woodland over two weeks during January 2014 and another the Humbug Scrub fire, in the Northern Adelaide Hills, burnt 13,000ha of scrub a year later. Though there would have been extensive damage to lichens in these two fires none of the media reports mentioned lichens! That may seem a rather banal comment, but when I was sampling lichens in Port Germein, which is close to the location of the Bangor Fire, one lady told me that many of the trees that were burnt by the fire had had lichens growing on them, and on a recent hike through the area she had noticed the lack of lichens.

6.3.2 Grazing and Browsing

Grazing and browsing by herbivorous animals may threaten lichen and bryophyte taxa on trunks and in the canopies of shrubs and smaller trees. Grassland and low woody vegetation can be destroyed through the effects of trampling by animals as well as browsing and grazing. In these circumstances recruitment of higher strata species will be reduced and will result in changes in the structure of woody vegetation and therefore cryptogam flora. For example, *Heterodea muelleri,* a common lichen in the grassy woodlands of the Tasmanian Midlands, underwent a dramatic decline due to increased cattle and sheep grazing (Brown *et al.*, 1994). While the argument above focuses on structural change to woody vegetation that can create new or diminished existing arboreal habitats for epiphytic lichens, they can also be threatened by the direct impact of ruminants that eat them (Section 6.2.1, Lesmerises *et al.* (2011) and McMullin *et al.* (2013)). Grazing and browsing by domestic stock are unlikely to be significant threats to epiphytic lichens in the study area. Most cattle grazing occurs on pastoral stations in the arid north of the state, and in the dairying area in the south east. Grazing in the Mid North and Southern Flinders Ranges is more-or-less restricted to sheep on pastoral stations and in these areas browsing salt bush *(Atriplex* spp.*)* and blue bush *(Marieana* spp.) communities will impact the lichen habitats that these low scrubby formations create.

6.3.3 Pollution

Air pollution is generally harmful to lichens and has been noted in many large cities with significant vehicle and industrial emissions, and in rural areas downwind of pollution sources (Section 2.6.1). Of particular importance are SO_2 and NO_x emissions. These two gases have been implicated in significant declines in several regionally red-listed lichens in southern and central Sweden, e.g., *Bacidia laurocerasi, Bryoria bicolor, B. smithii, Caloplaca lobulata, Collema* spp., *Eopyrenula leucoplaca, Evernia divaricate, Flavoparmelia caperata, Porina interjungens, Ramalina thrausta, Sticta* spp., and *Usnea* spp. (Thor, 1998).

There is limited information on the effects of air pollution on lichens in Australia. Scott *et al.* (1997) showed that near big cities, highways and around factories (i.e., areas with high levels of atmospheric pollution) there were a number of sensitive lichens that could not withstand air or water-borne pollutants in the lichen structure body and that they suffered reduced growth and high mortality. Sulphur dioxide, fluoride, lead and zinc were found to be the most harmful pollutants to lichens in their research.

South Australia is not a heavily industrialised state. The majority of the polluting industries are, and historically have been, around the Adelaide metropolitan area. However, there are point pollution sources in rural areas. The most notable ones in the context of this research are (i) the recently decommissioned and demolished Port Augusta Power Station (Johnson, 2015); and (ii) the notorious Nystar lead and nickel smelter at Port Pirie

(Nyrstar, n.d). Both of these have led to pollution plumes over the northern and central parts of the Southern Flinders Ranges respectively. Though in the case of Port Pirie the heavy metal pollutants would have precipitated close to the smelter itself. None of the study sites were located to the east of these two point sources.

6.3.4 Climate change

Climate change dramatically influences non-vascular species, as it does for many other plant and animal taxa. Species distributions may become restricted and may even become extinct locally or entirely (Warren *et al.*, 2001).

However, evidence about the response of lichens to climate change is somewhat ambiguous. Selva (1994) discovered that species richness in epiphytic lichen flora had become richer over time in northern New England and western New Brunswick due to changes in climate. Marini *et al.* (2011) found an association between climate on epiphytic lichen species richness in Italy, but they could not make generalisations about lichen responses to future global climate change. van Herk *et al.* (2002) showed that lichen flora in the Netherlands has changed over 22 years. They found that the proportion of arctic-alpine and boreo-montane species had declined in the lichen flora of the Netherlands, while that of sub-tropical species had increased. In a later study Aptroot and van Herk (2007) found further evidence of the effect of global warming on lichens in the Netherlands, specifically that epiphytic lichens are increasing.

Giordani and Incerti (2008) pointed out that climate change would affect certain lichen species as their abundance was strongly related to the mean annual temperature and rainfall. G. Insarov and Schroeter (2002) showed that lichen communities are strongly correlated with climate parameters and that predicted increases in mean surface air temperatures will affect their eco-physiological processes. Specifically, mean annual, maximum summer and minimum winter temperature will have impacts the net photosynthetic rate of lichens, and lead to physiological modifications. Haucka *et al.* (2007) pointed out that these controls occur at a microclimate scale as well as at the macroscale. Recently, Belinchón *et al.* (2014) has investigated lichen responses to moisture availability and cited research that epiphytic lichens were sensitive to distance from water.

The CSIRO and the Australian Bureau of Meteorology are at the forefront of climate change science in Australia. Kevin Hennessy — the principal research scientist at CSIRO – stated that “There is very high confidence [*sic.* given the available climate change predictions) that hot days will become more frequent and hotter.” and “…extreme rainfall events across the nation are likely to become more intense, even where annual-average rainfall is projected to decline.” (CSIRO, 2015). The mean annual surface air temperature across the continent has already increased by 0.9^{o}C since 1910. Of specific concern for this research is that the CSIRO (2015) predict that:

- there will be a reduction in winter and spring rainfall in southern mainland Australia (an area that includes the study area of this thesis); and

- fire weather will become more severe than it is at the present time. Fires along with droughts are the most significant natural hazards in South Australia.

The relationships between lichens and climate parameters at the regional and microscales (Chapter 5) indicate that the climate changes predicted by CSIRO are likely to have major impacts on lichen growth in the Adelaide Hills, Mid North and Southern Flinders Ranges. In particular, the predicted reduction in winter and spring rainfall is likely to have the most significant impact at the regional scale (Section 5.3). Increased fire severity could lead to increased mortality of trunk lichens and a reduction in the amount of habitat for re-establishment (Section 6.3.1).

6.3.5 Overexploitation

Overexploitation of lichens is probably a relatively minor threat in Australia, and it is likely that it does not affect epiphytic lichens. Macrolichen species can be overexploited if they are used for traditional medicine and food, which has occurred in some minority ethnic groups around the world. I have found no record of this in Australia. The removal and processing of lichens for the production of dyes used in clothing has also been identified as an important threat to lichens, but again there is no record of this from Australia. Scott *et al.* (1997) studied the conservation of non-marine lichens in Australia and noted the removal of lichen-encrusted bush rocks for landscaping of residential suburbs in Canberra was a threat to *Xanthoparmelia* sp. They also noted the removal and destruction of lichens by overenthusiastic lichen collectors and lichenologists.

6.4 Lichen conservation strategies

Scheidegger and Werth (2009) reviewed strategies for lichen conservation. Their work re-iterates the threats to lichens considered in Sections 2.6.1 and 6.3 of this thesis: i.e., a decline in quality or loss of habitats; habitats fragmentation; overexploitation; species invasion; climate change and air pollution. Many measures have been taken to protect lichens and these fall into two themes; habitat protection and protecting the few surviving members of a population.

Scheidegger and Werth (2009) identify that the first priority for lichen conservation is to protect populations of extremely rare species (either globally, *cf.* Table 6.2); of endemic species where a nation or a group of nations has a high level of international responsibility (Snäll *et al.*, 2005); or within a region (e.g. the red-listed lichens for Sweden and Tasmania noted elsewhere in this chapter). Snäll *et al.* (2005) argued that lichen populations need viable metapopulations, and dispersal mechanisms between them to be maintained for effective protection. To maintain effective protection in this context, three measures are required:

- the first, and the most crucial, is to protect the existing populations of extremely rare lichens;
- secondly, the areas that need to be conserved must be relatively close to each other to facilitate dispersal of fungal spores and algal cells, i.e. the metapopulation must be conserved. Suitable habitats without lichens also need to be conserved within the area of the metapopulation

so that their potential to host lichens can be maximised. In the context of the research conducted in this thesis, some species of trees, maybe even introduced species, provide more suitable habitat for lichens than other tree species (Section 4.4). Therefore, to achieve the second thread of conservation, active management is needed such as tree planting and the exclusion of exotic herbivores. In the Adelaide Hills, Mid North and Southern Flinders Ranges that would mean an emphasis on planting species with geographical ranges outside the study area as well as species native to the study area; and

- finally, many viable epiphytic lichen populations can only survive if tree felling is stopped or reduced. Again, this requires active management around a plan.

In some circumstances, habitats which are less than an optimal size will be afforded protection, though in these cases if the lichen populations reduce significantly the risk of local extinction will increase. However, it is better to protect the habitats and propagule pools. This will be expensive and time consuming (Scheidegger *et al.*, 1998), but if it is successful, it will protect habitats and increase lichen population sizes.

If the arguments above are considered as a whole it is clear that the area occupied by suitable habitat, habitat quality and connectivity between patches of suitable habitat, are the most important ecological measures that can be taken to conserve lichens. These tenets of conservation are usually considered in conservation planning, but if lichen conservation is to be successful lichens must be recognised as important components of ecosystems and conserved alongside other taxa (Scheidegger & Werth, 2009). This is not the case in most Australian states, including South Australia, at present.

While these points apply to lichen conservation in general, there may be issues that apply to epiphytic lichens specifically, e.g., Örjan *et al.* (2008) argue that tree age is a major factor in epiphytic lichen conservation. If a relationship between lichens and tree age holds, then the preservation of old-growth forest and woodland is important in the arsenal of lichen conservation tools. However, the relationships between lichens and tree age does not hold in all studies (Section 5.1) and was not proven in this research. Disputed research claims such as these will be problematic in arguing and then developing conservation strategies for epiphytic lichens.

6.4.1 Lichen conservation strategies in Australia

Research on lichen conservation is more advanced in Tasmania than in any other states, and this section borrows heavily from Tasmanian studies. Brown *et al.* (1994) comprehensively reviewed the protection of Tasmania's non-vascular plants and outlined the following strategy:

1. **The need for surveys**. Several scientists have undertaken vegetation surveys in the state (e.g. Jarman *et al.*, 1984; F. Duncan & Brown, 1985; Kirkpatrick *et al.*, 1988), and derived species distribution and habitat data. This scientific knowledge has provided a sound basis for conservation policies. However, there are constraints on surveys, these

would need to be borne in mind if this model was to be adopted in a much larger and, in some ways, logistically more difficult state like South Australia. The Tasmanian survey took approximately 50 years to finish — far longer than the decade that was initially proposed. An associated issue is that the taxonomic classification of flora was a significant task (this is addressed later in this chapter) and documentation was needed to remove samples for offsite identification.

2. **Reserve selection.** Kirkpatrick *et al.* (1980) and Kirkpatrick (1983) surveyed the vascular flora which is endemic to Tasmania and scored every 1km^2 on the basis of whether the endemic plants were rare and unprotected. They proposed seven areas that had key species and two reserves. The Working Group for Rainforest Conservation (1990) noted many Tasmanian agencies have cooperated in forestry community conservation by using the programme of environmental domain analysis. This guarantees that all forest types are represented in the reserve system. In Tasmania, the target was that the proportion of vegetation types to be reserved was in accordance with IUCN guidelines, i.e., a minimum of 5% for dry and wet sclerophyll forests, and 30% for rainforest. After implementation 60%, 20% and 12% of rainforest, wet sclerophyll and dry sclerophyll forests respectively that were not under a timber harvesting regime, i.e., 220,000ha of forest, were reserved. However, this approach to reserve selections is not without issues. For example, it is possible that the full range of microhabitats, which is essential in assessing lichen habitat, was not protected, and some of these could be lost through fire or climate

change anyway.

3. **A bank of scientific knowledge.** Podger, Bayly-Stark*, et al.* (1990) promoted the role of scientists, who had a bank of knowledge that could have been used to solve conservation problems, to the Forests and Forest Industry Council. In reality, however, there were not enough experts in non-vascular plants. This became a major stumbling block in convening evaluation panels. Issues around scientific expertise in non-vascular flora in Australia are expanded upon in Section 6.4.3.
4. **Off-reserve management.** Management by prescription on unreserved land is the way in which protection afforded by a reserve system is extended. In Tasmania for example, the application of the Forest Practices Code (Forestry Commission, 1989) is designated for the areas of logging, and a Management Decision Classification System was developed to protect ecological processes in native forests. However, no reports for non-vascular flora had been made by the early 1990s, although they were available for vascular plants and plant communities. Vertebrates and invertebrates have also been declared. As a result of these regulatory mechanisms, methods which are less harmful to ecosystems when exploiting forests were being investigated (McCormick & Cunningham, 1989), and it was found that in some situations, protecting individual species or communities is more important than creating and managing conservation reserves. A similar situation has arisen in Europe (Synge, 1981) where the targets of lichen conservation are buildings, stone walls, gravestones and individual trees.

6.4.2 Strategies for protecting non-vascular plants

The gold standard in conservation is to establish protection at three levels: genetic, species, and ecological processes. While these criteria are used extensively for vascular plants they can be applied, in many cases simultaneously, to non-vascular flora because they are ecologically linked.

However, non-vascular flora often occupies very small areas of an individual plant or vegetation community. It is impossible to manage all non-vascular plant microhabitats, and so the argument adopted is that protecting the vascular plant macrohabitats should be sufficient to protect the non-vascular plant microhabitats. Therefore, the prevalent reserve structures should clearly be suitable for non-vascular flora, especially for widespread, ecologically-tolerant species. It must also be noted, however, that some management techniques designed to maintain vascular plants and animal habitats may be harmful to non-vascular plants. For example, using controlled burns may not be harmful to woody vascular plants but can destroy corticolous trunk lichens; and clearance of an understorey in forests and woodlands will change the microclimate. Therefore, the modification of management practices to conserve non-vascular flora will require trade-offs with other conservation objectives if they are to also serve non-vascular plants.

Endemism, dispersal and conservation targets

Brown *et al.* (1994) found that 20% of the vascular plant species are endemic to Tasmania. However, the proportion of endemic non-vascular species is lower; at approximately 5% of the non-vascular flora on the island. Most of these are in reserves, e.g., *Siphulella,* a genus that is endemic to Tasmania and is now protected in the Tasmanian Wilderness World Heritage Area (Kantvilas *et al.*, 1992).

A number of lichen species that were considered endemic to New Zealand have been discovered in Tasmania (Galloway, 1985). In contrast, many Tasmanian endemic lichens have been found in New Zealand. Considering this as a biogeographical phenomenon, ecological responses to climate conditions in the South Island of New Zealand and Tasmania are similar but the distribution does raise questions about dispersal. Many of these so-called endemic species were described in the nineteenth century (Kantvilas, 1993). They probably require taxonomic revision.

This suggests that scientists need to be more attentive to biogeographical distributions of lichens that occur in small populations with a localised distribution. For example, a cosmopolitan species *Pseudocyphellaria aurata* is very rare in Tasmania but is not protected and may be locally at risk. *Pyxine nubila* which occurs in East Africa and the Middle East, has isolated occurrences in some private gardens in south-east Tasmania (Kantvilas & Jarman, 1991). This latter example begs questions of dispersal and also, because of its botanical interest, suggests it could become a conservation target.

Lack of distributional information can create ‘false conservation targets’ and given the knowledge gaps in lichenology the risk of this is high. The genus *Wawea* was recorded on soil and rotten wood in the subalpine Tasmania in 1963 and considered to be was new genus (Henssen & Kantvilas, 1985). However, studies two decades later, documented only one further population, which at that time confirmed its rarity. However, it has now been found on tea trees (*Leptospermum* spp.) in wet tea tree scrub and it has also been found in the scrub forests and moorland in the south-west of the island. Therefore, it has subsequently been proven that *Wawea* is a common lichen genus, although one with a series of localised distributions.

6.4.3 Practical issues associated with lichen conservation

The following issues have been identified in the context of conservation of non-vascular flora in Tasmania, but I would argue that they are common to all states in Australia and may be even more of an issue for these states.

Taxonomic constraints and lacunae in knowledge

There is a shortfall in the human and financial resources for the taxonomy work necessary in lichenology. This has led to knowledge gaps in Australia, as well as globally. An example of taxonomic work that is still required comes from Tasmania where 700 lichen species records exist (Kantvilas & Minchin, 1989). Scientists concede that this is only around two thirds of those on the island. Not only do new species need to be found and identified, but several herbarium specimens may be misidentified in the first instance and taxonomic revision is necessary. Of the 700 species recorded, some were detected in the same location (and may be duplicates) or have inadequate written records.

Typically, data gaps are filled through field surveys, which are expensive and often logistically constrained. In the case of lichens, the lack of specialists means that if collecting excursions can be made, there is a bottleneck later when it comes to identification and curation of hundreds of specimens are deposited at herbaria. Although many herbaria in Australia have a cryptogamist, classification is often only to genus or family level, and this level of identification is of limited value for conservation.

In Australia, not many scientists specialise in non-vascular flora. Nationally, taxonomic skills are inadequate, and few people are being trained. A key reason for this is that it is not an attractive area for professional biologists, or biologists in training. This is because research funding is very limited, which itself is due to the relatively low profile that lichens have within science or with the wider public.

The work of lichenologists does not stop at finding, identifying and curating new specimens. For example, there are calls on their time to contribute to government conservation panels in Tasmania which they find hard to service because of time demands. They face similar issues when training new staff or providing the wider public with basic lichen information. The lack of qualified lichenologists is limiting conservation strategies. This, of course, is not an uncommon problem globally with some taxa, and amateurs often fill this gap left by too few professional specialists. Though again the lack of scientists in this area means that there is a lack of people to check the accuracy of data or to train people.

6.4.4. Raising awareness of lichens

An important issue to tackle is to raise awareness of lichens among a wider public. It has been argued that several actions will increase people's awareness of lichens (Scott *et al.*, 1997).

In national parks, signboards and leaflets with information about lichens should be made available. These are rare, but one example where they are used is at the Remarkable Rocks site in Flinders Chase National Park on Kangaroo Island, South Australia. Here a signboard informs people who enter the park about the lichens growing on the rocks. Visitor centres are another avenue where information about lichens can be displayed and it goes without saying that park staff should be educated in this area and be available to answer questions from interested members of the public.

Teaching about lichens in primary, secondary and tertiary education as part of general science, as well as Biology degree programs, would widen interest in, and knowledge about lichens. While this can cover the biology of lichens, teachers should also talk about their many, often exotic, uses to interest and intrigue people. Many schools and campuses have trees, many of which are likely to have lichens growing on them unobserved by students (and staff!). These are opportunities that need to be taken.

Beyond formal education, the science and natural history media should be encouraged to develop material on lichens. This may be done around their uses. Anecdotally, while undertaking this research I was filmed showing and talking about the lichens growing on trees at the Hallett study site for the science channel of Vietnamese national television. These programs should also show the micro-level intricate beauty of lichens. Many lichenologists have entered this field through photographing lichens in their teens. While I was doing this PhD., my supervisor went to an exhibition of lichens at the Field Museum in Chicago curated by Professor Robert Lücking. Yet another avenue for introducing lichen to the public, but even as Professor Lücking wrote in the introduction to the exhibition, this was a first for the Field Museum.

Some species are inherently useful. Some lichens form soil crusts which can protect and promote soil stability and reduce wind and water erosion in semi-arid areas. This capability has currency in Australia and could be broadly promoted to land owners and managers, and conservation and regulatory bodies, e.g., through The Murray-Darling Basin Commission. Broader engagement can be encouraged through organisations such as Earthwatch, the National Threatened Species Network and Bioblitzes. Public guidebooks and apps full of pictures of beautiful lichens, that would enable people to identify lichens when bushwalking and when partaking in other outdoor activities would also be helpful.

6.4.5 Applying knowledge about conservation strategies to South Australia

The gaps in ecological, taxonomic and distributional knowledge about epiphytic lichens in South Australia are large, as has been noted elsewhere in this thesis. This is a serious impediment to conservation planning around lichens and other non-vascular taxa.

A long term conservation strategy for South Australia is encapsulated in *No Species Loss (A Nature Conservation Strategy for South Australia 2007-2017)* (Department for Environment and Heritage, 2017). The authors argue in detail for bio conservation and include lichens in that argument. Such recognition is an important starting point for developing lichen conservation strategies in the state, along the lines of Tasmania or elsewhere in the world. The report notes that 320 lichen species have been found in South Australia, but as no species are considered to be threatened, arguing for lichen conservation is potentially problematic. Perhaps with more surveys, and more taxonomic and ecological recording we will find more lichens in the state and maybe discover that some are threatened and in need of conservation status.

6.5 Summary

There has been relatively little research on lichen conservation in Australia. However, Tasmania is an exception, and much of the work which has been analysed and evaluated in this chapter in the context of its application to South Australia, comes from that state.

No lichens appear on the Australian red list, though four lichens have conservation status in Tasmania. Schedules 7, 8 and 9 of the South Australia National Parks and Wildlife Act (Government of South Australia, 2017) do not list any lichens in the endangered, vulnerable and rare categories.

The most important threat to lichens in the study area is climate change, with changes in habitat, fire and air pollution being of secondary importance. Climate change predictions to the Adelaide Hills and Mid North are for hotter temperatures generally and decreased winter and spring (wet season) rainfall. The combination of these parameters suggests a warmer and drier regional climate, and drier tree microclimates. Given the findings in Chapter Five, this will reduce lichen occurrence and cover. Given these climate predictions fire frequency and intensity will increase, which will have a negative impact on trunk lichens. Air pollution plumes for the industrial area around Port Adelaide and the Nystar smelter at Port Pirie will depress lichen populations, but only locally; and the massive woodland clearance of the past is in reality history.

The lichens were collected from a mix of trees whose native ranges are in the Adelaide Hills, Mid North and Southern Flinders Ranges and were sampled in reserves along with introduced trees. Therefore, it is impossible to judge the extent to which alteration of habitats in natural woodlands will affect lichens, though because most bush clearance has stopped in the state this is likely to be minimal.

However, in Section 4.4 a tendency towards more lichens growing on trees that had been introduced to the areas, from elsewhere in Australia or overseas, was noted. This indicates that threats to reserves and other exotic plantings are more important than those affecting natural woodland in the context of lichen conservation. Climate change is undoubtedly the main threat to vegetation in reserves.

The newly launched long term conservation strategy for South Australia — *No Species Loss (A Nature Conservation Strategy for South Australia 2007-2017)* (Department for Environment and Heritage, 2017) – has provision for non-vascular plant conservation. However, to bring the lichen element of the conservation strategy to fruition more lichen studies (collecting, taxonomy and ecological studies) need to be conducted. In that regard, the conservation strategy will come up against the low number of non-vascular plant scientists and taxonomists in the state. That requires activities to raise awareness of lichens amongst the public as well as in formal education.

CHAPTER SEVEN

CONCLUSIONS

7.1 Overview

This study builds on other research on corticolous lichens that has been referenced throughout this thesis; and in doing so attempts to extend this niche of lichenology by conducting research along a warm temperate sub-humid to arid gradient. In essence it examined corticolous lichen autecology along a climatically-controlled ecotone. It was done this by designing and applying a sampling plan to 37 study sites and 621 trees from the central Adelaide Hills, through the Mid North and into the Southern Flinders Ranges in South Australia. The area covered was approximately 22,200 km^2.

The research focused on three broad overarching questions:

1. What are the relationships between epiphytic lichens and trees as substrates in the Adelaide Hills, Mid North and Southern Flinders regions of South Australia?

2. What are the relationships between epiphytic lichens and climate in the Adelaide Hills, Mid North and Southern Flinders regions of South Australia?

3. Does the occurrence of lichens differ between native and introduced trees?

In addition, the threats to corticolous lichens and their conservation status in Australia were examined briefly.

7.2 Summary of findings

The detailed findings of the empirical aspects of the study — the three questions above – are revealed in Chapters Four and Five, and the qualitative analysis of threats to, and conservation of, corticolous lichens is presented in Chapter Six.

Five corticolous macrolichens — *Xanthoria parietina*, the *Caloplaca holocarpa* group, *Physica aipolia*, *Lecidella elaeochroma* and *Chrysothrix xanthina* – were found in the study area. Lichen species richness varied from 0 to 3 lichens per tree. The 32 trees that had two or three different macrolichens growing on them comprised a relatively high number of *Celtis australis* and *Melia azedarach* trees; both of which have been introduced to South Australia. However, it is not clear if the high frequency and greater species richness of these trees is due to the nature of the tree species or the characteristics of the limited number of sites where these lichen-infested trees were growing.

Research Question 1: *What are the relationships between epiphytic lichens and trees as substrates in the Adelaide Hills, Mid North and Southern Flinders regions of South Australia?*

The lichens sampled across all sites in the study area appeared to be relatively independent of tree diameter class. However, though there was no clear diameter-dependent relationship, lichen occurrence peaked on trees with diameters between 15.1 and 45cm diameter. Lichen occurrence also appeared to be independent of tree height. The inference that can be made taking these two findings taken together is that lichen occurrence is independent of tree age for all tree species sampled, as well as for some of the species/genus groups with a high number of individuals, e.g., the *Callistemon* and *Fraxinus* genera and *Eucalyptus torquata.*

Three bark properties tested influenced lichen occurrence differently, although the inferences that could be made were not always supported by statistical testing. Lichen cover appears to increase as bark becomes less acidic, this was supported by a weakly positive but statistically significant correlation. Though it must be noted that the range of bark pH was limited to 3.13-7.08 and, even within this range, lichens were rare on highly acidic bark of <4.5. The relationship between bark roughness and lichen occurrence also showed a weak but statistically significant association, both for all trees and trees with lichens. However, in these two cases the relationships were negative indicating that as tree bark becomes rougher lichen occurrence is reduced.

Perhaps the low strength of the association between lichen occurrence and bark roughness is misleading, because trees which regularly shed their bark have few lichens on the newly exposed smooth bark. Bark shedding was more strongly related to lichen occurrence than either pH or roughness as indicated by Yates χ^2 and Fisher's Exact tests. It was clear that the five macrolichens sampled had a strong preference stable bark surfaces. Bark shedding is related to bark roughness in that trees that have recently shed bark are smooth, they are also almost free of lichens.

In summary, lichen occurrence is likely to be greater on trees with bark pH at the higher end of the 4.5-7.1 range that do not shed bark and also do not develop rough bark surfaces with many deep indentations.

Research Question 2. *What are the relationships between epiphytic lichens and climate?*

In terms of tree microclimate, statistically significant differences in lichen cover between the north, east, south and west aspects for all trees sampled were found for all trees with lichens on them, for trees with *X. parietina*, and for *X. parietina* growing on *Fraxinus* sp., but not for *C. holocarpa. Post-hoc* Dunn's tests showed that the most frequently occurring pair of significantly different aspects was north and south (40.6% of N-S pairs tested), and that all other significantly different pairs included the south aspect. This finding stresses the importance of incident solar radiation and the relative humidity of the trunk microclimate in relation to lichen growth.

Canopy lichens were also recorded in all trees sampled. The occurrences of trunk and canopy lichens at the 37 sites were found to be significantly different when the Wilcoxon signed-rank test was applied. Approximately three-quarters of the trees sampled fell into one of two categories; trees with lichens on the trunk and in the canopy, or trees with no canopy or trunk lichens. Yet 14.8% of trees had canopy lichens but no trunk lichens, and 7.6% of trees had trunk lichens but no canopy lichens. The majority of trees with canopy but no trunk lichens was greatest at intermediate rainfall sites. The inference drawn from this was that lichens begin to establish at atmospheric humidity threshold that is lower than that required for trunk lichens on the same trees. Following this, the occurrence of canopy lichens on these trees at medium rainfall sites is likely explained by the slightly reduced levels of solar radiation and greater frictional resistance to wind in the canopies compared to the trunks of these trees.

In terms of regional-scale climate-lichen relationships, *X. parietina* frequency on all trees, was found to increase with:

- increasing annual, summer and winter precipitation;
- decreasing annual, summer and winter temperatures; and
- decreasing annual, summer and winter evaporation.

These results are intuitive and fit existing ecological theory and are indicative that *X. parietina* — the most commonly occurring lichen in the study area — prefers moister (or more humid) and cooler climates. This argument can be strengthened by the fact that the strongest relationships between lichen occurrence and frequency are with evaporation, rather than with either precipitation or temperature. This appears to indicate that it is not the amount of precipitation that falls at a site that is important, but rather its partitioning into direct precipitation, stemflow and evaporation or evapotranspiration. That, in turn, suggests that a simple water balance approach to regional-scale relationships between lichen occurrence or frequency and climate measurements might provide statistically stronger relationships based on partitioning of water in the woodland ecosystems that contain these lichens. The potentially difficult to explain weak negative correlation between *X. parietina* frequency and summer rainfall for all sites in this study, suggests that trees in low summer rainfall locations may have greater lichen frequencies. This contradicts Ellis *et al.*'s (2007) findings from Europe.

In summary, lichens are more likely to be found in the canopies and on the trunks of trees in the more humid and cooler Adelaide Hills, whilst in the arid parts of the Mid North and Southern Flinders Ranges the majority of trees have neither canopy nor trunk lichens. Lichen occurrence on trees in the medium-rainfall sites, which are mainly in the Mid North, have trees with canopy and trunk lichens as well as trees with neither. More importantly, the majority of trees that only have canopy lichen were found in this part of the study area indicating the possible existence of a humidity microclimate threshold for lichen establishment that is influenced by trees canopies disrupting insolation pathways and reducing wind flow through frictional resistance. However, a caveat related to the findings discussed above is that some of these trends are not statistically significant and require further research to confirm their veracity.

Research Question 3. *Does the occurrence of lichens differ between native and introduced trees?*

There is statistically significant evidence from Yates χ^2 and Fisher's Exact tests to contingency tables of all individuals sampled, as well as all species sampled that the probability of lichens growing on introduced trees is higher than it is for lichens growing on species native to the Australian mainland. Though this aspect of lichen occurrence has not been investigated before to the author's knowledge, it was something that was discussed in supervisory meetings during thesis planning and for that reason it was included in the sampling plan (see Chapter 3). This is a potentially very important finding from this thesis, in fact it is likely to be the most important finding moving forward. However, it requires significant further research to verify it, and if it is confirmed, to explain how this dichotomy arises. Is it due to differences in bark properties between these two groups of trees given that a higher proportion of Australian native trees shed bark than introduced trees, or were lichens introduced on ornamental exotic trees and what is being witnessed now is their dispersal into the local tree flora?

There are a number of lines of research that could be used to investigate this novel finding further, specifically to see if this phenomenon is related to the trees and lichens studied in this area or is a more generalisable. In the author's opinion the following research would be the logical next steps at the present time:

- examining lichen occurrence on only the most frequently occurring native and non-native trees in the area to eliminate any potential statistical biases created by including less frequently occurring trees;
- as almost all the trees are amenity plantings, there is the probability of investigating the local histories of when trees were planted and where the tree stocks were obtained from to examine growth rates and the possibility of introduction of lichens from nursery stock; and
- replicating this research along other semi-arid gradients, e.g., in Western Australia and New South Wales, and in wetter climates in Australia where different trees and lichen species are likely to be present.

Conservation status

Though it was not one of the three major research questions, the threats to lichens, particularly, epiphytic lichens were reviewed in the context of how that is reflected in their conservation status? There has been relatively little research on lichen threats and conservation in Australia, with the exception of Tasmania. Consequently, the review and evaluation of threats and conservation in this thesis and their potential application in South Australia is based in the Tasmanian situation. While no lichens appear on the Australian red list, in terms of conservation the research that has been carried out in Tasmania has resulted in a number of conservation actions, one of which is that four lichens now have conservation status in that state.

The most important threat to lichens in the study area is climate change, with changes in habitat, fire and air pollution being of secondary or more local importance. CSIRO and Australian Bureau of Meteorology climate change predictions for the area investigated are for significantly warmer and drier regional climate by the mid 21st Century. In particular, winter and spring rainfall will decline and this is likely to have a major effect on lichen growth. Under the predicted future climate conditions fire frequency and intensity will increase, which will impact on trunk lichens. Air pollution plumes for the industrial area around Port Adelaide and the Nystar lead and nickel smelter at Port Pirie will likely continue to depress lichen populations locally downwind.

It was not possible to judge the extent to which habitat alteration in natural woodlands will affect lichens, even though most bush clearance in the state has been curtailed, because the research focussed on trees in reserves and similar locations. However, because there is statistically sound evidence that more lichens grow on trees that have been introduced to the study area, threats to reserves and other exotic plantings may be more important than those to natural woodland in the context of lichen conservation in South Australia. Climate change is undoubtedly the major threat to vegetation in reserves, as it is to remnant bush.

Schedules 7, 8 and 9 of the South Australia National Parks and Wildlife Act do not list any lichens in the endangered, vulnerable and rare conservation categories. However, the recent long term conservation strategy for South Australia — *No Species Loss (A Nature Conservation Strategy for South Australia 2007-2017)* – has provision for conserving non-vascular plants. Nevertheless, to bring the lichen element of this conservation strategy to fruition, more lichen research (collecting, taxonomy and ecological studies) needs to be conducted in the state. In that context, the conservation strategy will come up against the lack of non-vascular plant scientists and taxonomists, which is, in part, due to the low profile of lichens compared with many other taxa. This situation requires activities to raise awareness of lichens amongst the public as well as through formal and non-formal education.

7.3 Limitations

To a large extent this research had an exploratory nature, as very little research had been conducted previously on corticolous lichens in arid and semi-arid areas. Therefore, on reflection, it is inevitable that a number of limitations with this research investigation have been identified. These are enumerated below with the intention that future researchers can accommodate or overcome them.

1. Although the number of trees sampled was high (621), sampling more trees would have strengthened the statistical tests. The main argument supporting this statement is that with a medium-to-large minority of trees having no lichens some tests might have been compromised.
2. The analysis of bark chemistry was restricted to pH. While pH is generally accepted as a valid reductionist approach to the chemistry of a substrate in ecology, a more detailed analysis of the chemicals in bark would likely reveal which chemicals have the greatest influence on lichen establishment and growth. If such an analysis had been conducted, firmer statements about bark as a substrate could have been made. However, funds were not available to conduct the range of tests required (based on previous research) for the number of trees sampled given the other costs, particularly travel, involved in this project.
3. The sampling scheme focussed on reserves and other ornamental plantings for the reasons explained in Chapter 3. While this enabled lichen growth between native and non-native trees to be evaluated; it meant that areas of remnant bush, which have primacy in the minds of Australian botanists and ecologists, were not investigated. Future studies should combine remnant bush and reserves in any sampling scheme. A failing of this research is, therefore, that the researcher cannot address the issues of threats to lichens, let alone their basic autecology, in tracts of native vegetation
4. The study focussed in macrolichens which, in part, was due to its exploratory nature. Further research is required to assess the

autecology of microlichens in the study area.

5. The finding that lichen occurrence is significantly different between introduced and native trees was finally revealed late in the study, though it was part of the sampling plan. In retrospect, had this been known (or if it had been found elsewhere by other researchers) other research elements could have been added to the project which would have enabled this potentially important finding to be discussed in context. For example, local histories of tree planting in the reserves sampled could have been elucidated from district and town council records and through oral histories in each of 37 townships sampled. Though it must be added that the additional amount of time and effort this would have required would likely have been beyond that available in a PhD thesis.

7.4 Implications of the study

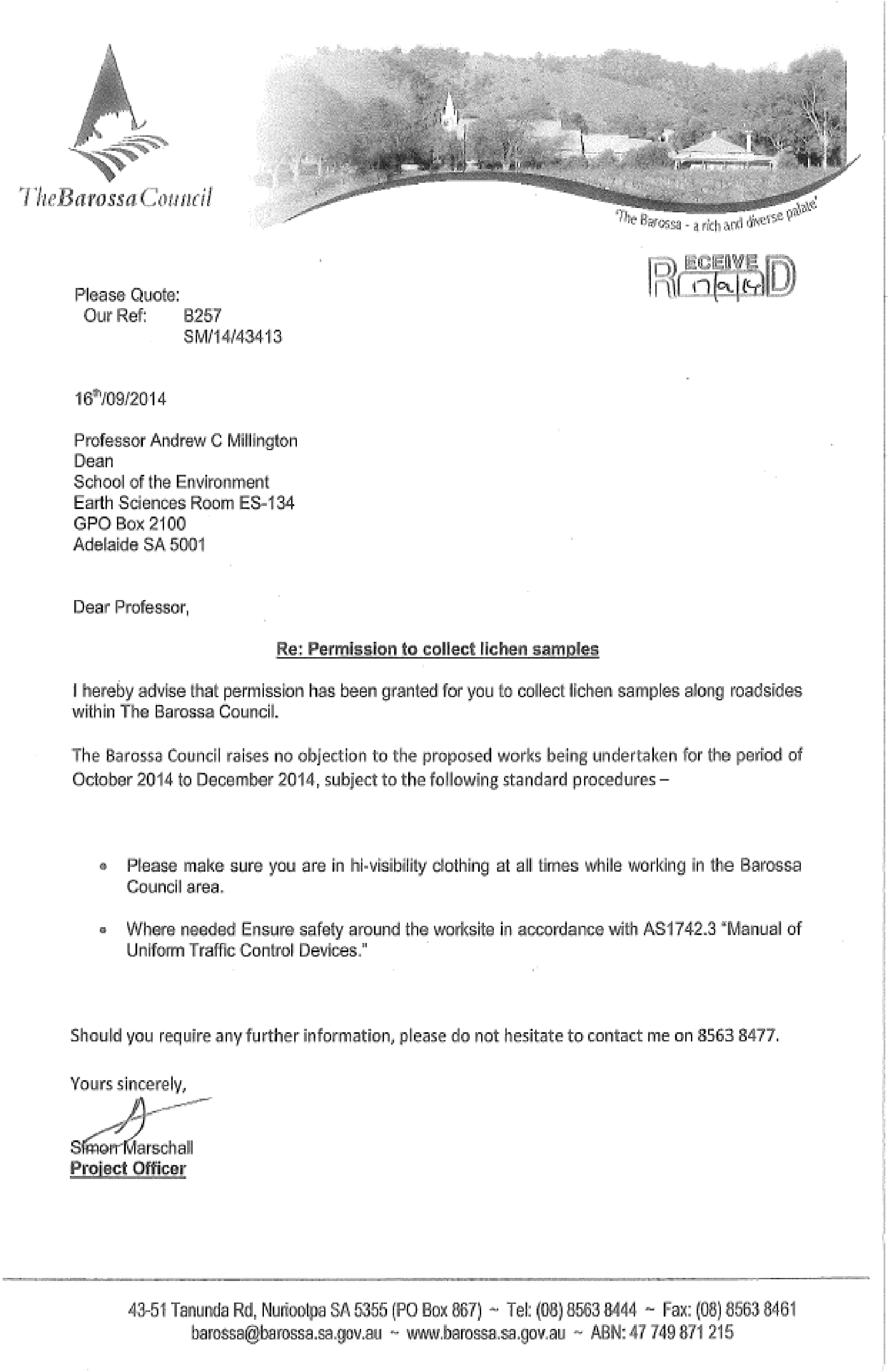
Many of the confirmed relationships between lichens and tree properties, and lichens and climate from other research are proven and intuitive and are broadly supported by this research. However, this research was conducted along a semi-arid to arid climate gradient and to the author’s knowledge corticolous lichens have not been investigated previously along a climatic gradient similar to this. Therefore, the importance of this research is that it extends significantly the understanding of corticolous lichens in a different climate zone or zones.

The statistically significant finding that lichens occur on trees that are not native to the Adelaide Hills, Mid North and Southern Flinders Ranges (and have therefore been planted as ornamentals) in preference to Australian natives is a new and potentially very important finding. It clearly requires further research. First to prove that this preference between trees occurs in other areas and then, if proven, to explain how it had arisen. If the tendency is for introduced trees to have a greater lichen flora than native trees, interesting and novel lines of investigation will hopefully explain it. This finding will also have an important implication for lichen conservation; which will need to be promoted through adjustments in how reserves and street trees are managed by local councils, and probably a major shift in the attitudes of people who want to remove the non-native elements of region's or location's flora.

That leads to the final implication, which is the lack of recognition of the value and importance of lichens. Returning to the questions, I was asked by people during lichen collecting trips, such as "What are those things you are collecting?" and "Do they harm the trees?" (see Section 1.1). These questions would not be asked if public awareness of lichens was greater. So, they are in fact not so much questions but statements of ignorance. They reflect the low status of lichens in the Australian scientific community as well as amongst the public. If I were working in this region again and somebody asked me about lichens, rather than answer their questions I would be able to say:
"*Most lichens in this area grow on the southern and eastern aspects of trunks and in the canopy of trees, with relatively smooth bark that does not peel away and is slightly acidic to neutral in the Adelaide Hills. There the climate is relatively cool and humid, and lichens prefer those conditions. But, in the arid northern parts of the Southern Flinders Ranges and Mid North lichens are rare.*

The climate is generally too hot and dry for lichens. Nonetheless, they do occur in these drier northern areas. However, even here they will also be generally be found on the southern and eastern aspects of trunks and in the canopy of trees, with relatively smooth bark that does not peel away and is slightly acidic to neutral."

Appendix 3.1 Sample permission letter, and the local government authorities that granted permission to undertake this research in Adelaide Hills and Mid North region during 2013-2016



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SM/14/43413

16th/09/2014

Professor Andrew C Millington
Dean
School of the Environment
Earth Sciences Room ES-134
GPO Box 2100
Adelaide SA 5001

Dear Professor,

Re: Permission to collect lichen samples

I hereby advise that permission has been granted for you to collect lichen samples along roadsides within The Barossa Council.

The Barossa Council raises no objection to the proposed works being undertaken for the period of October 2014 to December 2014, subject to the following standard procedures –

- Please make sure you are in hi-visibility clothing at all times while working in the Barossa Council area.
- Where needed Ensure safety around the worksite in accordance with AS1742.3 "Manual of Uniform Traffic Control Devices."

Should you require any further information, please do not hesitate to contact me on 8563 8477.

Yours sincerely,

Simon Marschall
Project Officer

43-51 Tanunda Rd, Nuriootpa SA 5355 (PO Box 867) ~ Tel: (08) 8563 8444 ~ Fax: (08) 8563 8461
barossa@barossa.sa.gov.au ~ www.barossa.sa.gov.au ~ ABN: 47 749 871 215

Local government area	37 Townships
Adelaide Hill	Bridgewater, Gumeracha, Lobethal, Mylor, Stirling, Macclesfield, Meadow
Adelaide Plains	Two Wells
Barossa	Angaston, Lyndoch, Springton, Williamstown
Clare and Gilbert Valleys	Auburn, Clare, Rhynie, Tarlee
Flinders Ranges	Hawker
Goyder	Burra, Eudunda, Hallett, Robertstown, Terowie
Light	Freeling
Mid Murray	Truro
Mount Remarkable	Port Germein
Northern Areas	Jamestown, Spalding
Orroroo Carrieton	Carrieton, Orroroo
Peterborough	Oodla Wirra, Peterborough
Port Augusta	Port Augusta
Port Pirie	Crystal Brook
Port Wakefield	Port Wakefield, Snowtown
Town of Gawler	Gawler

Appendix 3.2 Site photographs of the 37 sample sites in Adelaide Hills and Mid North region during 2013-2017. There are three letters in each photo showing the abbreviation of the town that samples collected, and the number is the tree number.

ANG 1

ANG 15

AUB 10

BRI 01

BUR 15

CAR 06

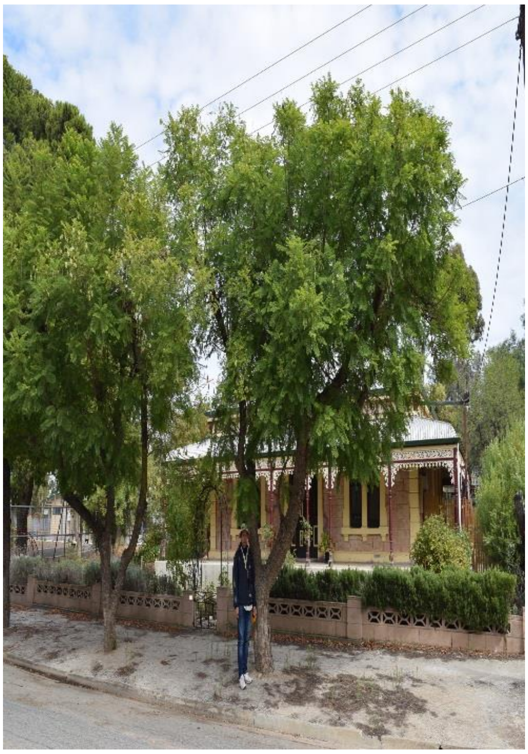
CAR 07

CLA 10

CRY 24

EUD 02

FRE 06



FRE 20

GAW 10

GUM 02

HAL 07

HAW 16

JAM 01

JAM 12

LOB 01

LYN 10

MAC 01

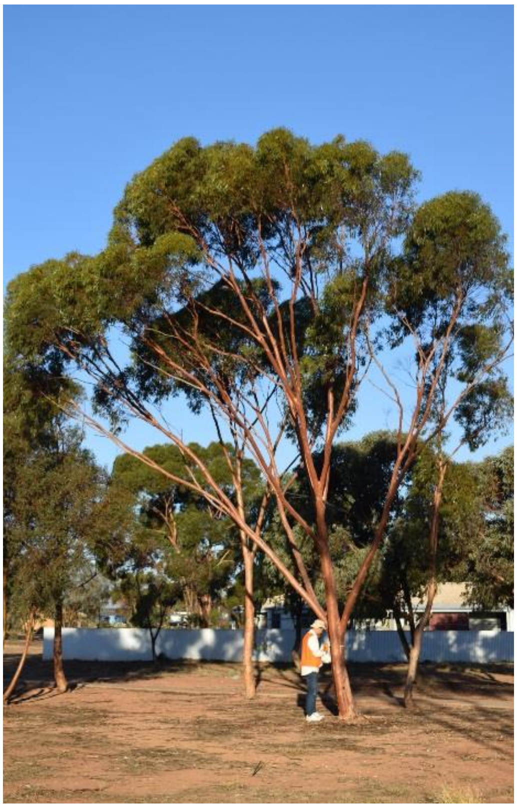
MEA 10

BAR 10

MYL 10

OOD 08

PET 09



AUG 8

GER 9

WAK 10

RHY 10

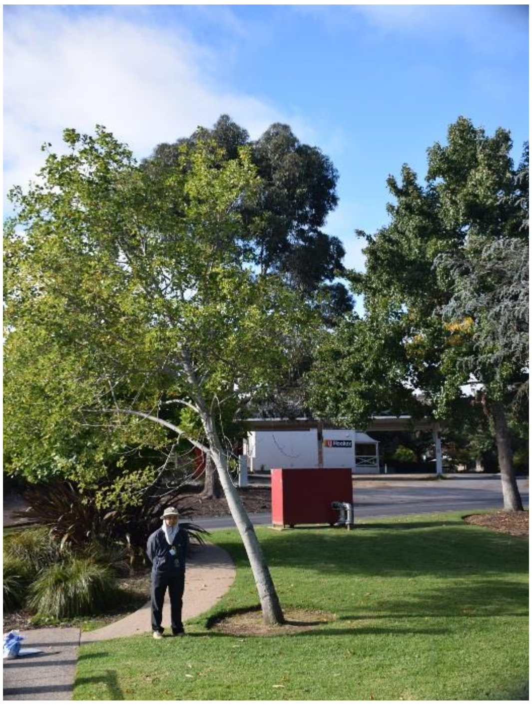
ROB 03

SNO 09

SPA 01

SPA 06

SPR 10



STI 01

TAR 10

TER 01

TRU 10

TWO 10

WIL 10

Appendix 4.1 List of tree species and genera sampled with authorities and key sources.

The authoritative sources listed for Australian natives start with a national listing, (e.g., Atlas of Living Australia, http://bie.ala.org.au/species/http://id.biodiversity.org.au/instance/apni/952457 for *Acacia anuera*). This is followed by a listing from the state where the tree is native or most frequently encountered (e.g., for *Acacia pendula* which is widespread in NSW, the Royal Botanic Gardens, Sydney is used http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Acacia~pendula). If the tree is also native to the study area, a South Australian authority is used such as the State eFlora, SeedbankSA or the Australian Arid Lands Botanic Garden at Port Augusta.

For trees introduced to Australia either an authoritative national source from Australia is used, as above, or an appropriate external authority (e.g., *Acer palmatum*, USDA Plant Database *https://plants.usda.gov/core/profile?symbol=ACJA2*)

The common given for each species, is that most frequently used in South Australia, if the tree is found in the state.

This detailed listing is only done for identified species, for those trees only identified to genus level a listing can be found at the end of this appendix

Species listing

Acacia anuera F. Muell e Benth. 'Mulga Wattle' widespread in arid Australia, including study area.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/instance/apni/952457

Australian Arid Lands Botanic Garden

http://www.australian-aridlands-botanic-garden.org/general/plants/p_spec/mulga.htm

Acacia beckerli Tindale subsp. *beckerli* ‘Barrier Range Wattle’ Arid parts of South Australia and NSW

Atlas of Living Australia

http://avh.ala.org.au/occurrences/search?taxa=Acacia+beckleri+subsp.+beckleri&q=&fq=&wkt=&lat=&lon=&radius=&offset=20&max=20#tab_mapView
SA Seedbank http://saseedbank.com.au/species_information.php?rid=116

Acacia iteaphylla F. Muell e Benth. ‘Willow-leaved Wattle’ widespread in South Australia (including study area), NSW, Victoria and SW Western Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2919200

SA Seedbank
http://www.saseedbank.com.au/species_information.php?rid=164

Acacia pendula A.Cunn. ex G. Don ‘Weeping Myall’ Native to Australia east of the Great Dividing Range.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2898562

Royal Botanic Gardens, Sydney http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Acacia~pendula

Acacia salicina Lindl. ‘Broughton Willow or Cooba’ Widespread in all states except Tasmania and Western Australia south of the tropics, with prevalence in drier parts.

Australian National Herbarium
http://www.anbg.gov.au/acacia/species/A-salicina.html

SA Seedbank
http://www.saseedbank.com.au/species_information.php?rid=217

Acacia saligna (Labill.) H. Wendl. ‘Western Australian golden wattle or cujong’ Native to SW Western Australia

Florabase https://florabase.dpaw.wa.gov.au/search/quick?q=Acacia+saligna

Acacia stenophylla A. Cunn. Ex Benth. ‘Eumong’ Widespread in Queensland, western half of New South Wales, the far northwestern fringe of Victoria and parts of northeastern and southeastern South Australia. There is a disjunct population on the Northern Territory-Western Australia border.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2906447

SA Seedbank
http://www.saseedbank.com.au/species_information.php?rid=227

Acer japonicum cultivar (A. japonicum Thurb.) ‘Amur or Japanese Maple’ Native to Korea and Japan. Introduced to Australia as an ornamental tree.

USDA Plant Database https://plants.usda.gov/core/profile?symbol=ACJA2

Atlas of Living Australia

http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2909487#overview

Acer negundo L. 'Boxelder, USA; Ash-leaved Maple, Australia' Native to North America.

USGS Plant Database
https://plants.usda.gov/core/profile?symbol=acne2

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2901529#overview

Agonis flexuasa (Willd.) Sweet. 'Peppermint Tree' Native to SW Western Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2912734
Florabase (WA)
https://florabase.dpaw.wa.gov.au/browse/profile/5316

Allocasuarina muelleriana (Miq.) L.A.S.Johnson 'Salty Oak-bush' Eyre Peninsula to western Victoria, including the mid North and Flinders Ranges.

Atlas of Living Australia
https://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2888252

SA Seedbank http://saseedbank.com.au/species_information.php?rid=321

Araucaria heterophylla (Salisb.) Franco 'Norfolk Island Pine' Endemic to Norfolk Island.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2911371

Betula pendula Roth. ‘Silver Birch, Europe; European Birch, Australia’ Native to northern Eurasia.

Kew Gardens http://www.kew.org/science-conservation/plants-fungi/betula-pendula-silver-birch

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2887252

Brachychiton populneus (Schott & Endl.) R.Br. ‘Kurrajong’ Native to Eastern Australia.

Atlas of Living Australia

http://bie.ala.org.au/species/http://id.biodiversity.org.au/instance/apni/948601
Royal Botanic Gardens Sydney http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Brachychiton~populneus

Callistemon viminalis (Sol. Ex Gaertn.) G.Don. *"Harkness*” ‘Bottlebrush Gawler Hybrid’

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2903693

Callitris collumenaris F.Muell. Slender Cypress-pine. Widespread in Australia

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/instance/apni/886170

Callitris gracilis R.T.Baker. ‘Murray Cypress Pine’ Southern South Australia and Victoria, including Adelaide Hills.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2893814
SA Seedbank http://saseedbank.com.au/species_information.php?rid=909

Callitris preissii Miq. 'Rottnest Island Pine' Native to Rottnest Island, Western Australia.

IUCN Red List of Threatened Species
http://www.iucnredlist.org/details/42207/0
Florabase https://florabase.dpaw.wa.gov.au/browse/profile/96

Casuarina cristata Miq. 'Belah' Native range extends form Central Queensland to southern New South Wales.

Atlas of Living Australia http://bie.ala.org.au/search?q=Casuarina+cristata\
Royal Botanic Gardens Sydney http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Casuarina~cristata

Casuarina glauca Sieber ex. Spreng. 'Swamp Oak' Native range is coastal Queensland and New South Wales.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/289312

Royal Botanic Gradens Sydney
http://saseedbank.com.au/species_information.php?rid=1000

Celtis australis L. 'European Hackberry or European Nettle Tree' Native to Mediterranean Europe and Asia, and North, naturalised in south eastern Australia

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2891680

Coprosma repens A. Rich. 'Mirror Bush' Native to New Zealand, introduced to Coastal New South Wales, Victoria and South Australia.

Flora of New Zealand
http://floraseries.landcareresearch.co.nz/pages/Taxon.aspx?id=_3f21850b-8f3f-4723-ae60-56cbb420ec3a&fileName=Flora%201.xml#_3f21850b-8f3f-4723-ae60-56cbb420ec3a

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2918878

Corymbia citriadora (Hook.) K.D.Hill & L.A.S.Johnson 'Lemon-scented Gum' Mainly in coastal Queensland and New South Wales.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2912509

Corymbia ficifolia (F.Muell.) K.D.Hill & L.A.S.Johnson. 'Albany Red Gum' Native to Western Australia

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2904317
Florabase https://florabase.dpaw.wa.gov.au/browse/profile/17103

Cupressus sempervivens L. Italian Cypress. Native to the eastern Mediterranean region, with a disjunct population in Iran.

Missouri Botanic Garden
http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a162

Eucalyptus behriana F.Muell. 'Broad-leaved Box' Endemic to south east Australia. Australia.

Atlas of Living Australia
http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a162

Royal Botanic Garden, Sydney http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Eucalyptus~behriana

Eucalyptus calycogona Turcz. 'Gooseberry Mallee or Square-fruited Mallee' Endemic to Western Australia.

Florabase https://florabase.dpaw.wa.gov.au/browse/profile/5579

Eucalyptus camaldulensis Dehnh. 'Murray Red Gum' Native to Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2921040
SASeedbank http://saseedbank.com.au/species_information.php?rid=1796

Eucalyptus cladocalyx F. Muell. 'Sugar Gum' Native to south east Australia, including the study area.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/7587088
SASeedbank http://saseedbank.com.au/species_information.php?rid=1802
Eucalyptus cneorifolia DC. 'Kangaroo Island Narrow-leaved Mallee' Native to South Australia.
SASEedbank *http://saseedbank.com.au/species_information.php?rid=1803*

Eucalyptus. dumosa A.Cunn. ex J.Oxley 'Dumosa Mallee' Range extends from the Eyre Peninusla to inland southern New South Wales and western Victoria, includes the mid North and Flinders Ranges

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2894653

SASeedbank http://saseedbank.com.au/species_information.php?rid=1814

Eucalyptus erythrocorys F.Muell. ‘Red-cap Gum or Illyarrie’ Native to Western Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2909951
Florabase https://florabase.dpaw.wa.gov.au/browse/profile/5638

Eucalyptus foecunda Schauer. ‘Narrow-leaved Mallee’ Native to Western Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/instance/apni/954236.
Florabase https://florabase.dpaw.wa.gov.au/browse/profile/5649

Eucalyptus forrestiana ‘Diels Fuchsia Gum’ Native to Western Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2915740
Florabase https://florabase.dpaw.wa.gov.au/browse/profile/5652

Eucalyptus gillii Maiden. ‘Curly or Arkaroola Mallee’ Native to South Australia and New South Wales, including study area

Atlas of Living Austraia.
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/5269532
SASeedbank http://saseedbank.com.au/species_information.php?rid=1821

Eucalyptus gracilis F.Muell. ‘White Mallee’ Range extends from the Western Australia to inland southern New South Wales and western Victoria, includes the mid North and Flinders Ranges

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2905257
SASeedbank http://saseedbank.com.au/species_information.php?rid=1827

Eucalyptus gunnii Hook. f. ‘Cider Gum’ Native to Tasmania.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/instance/apni/853388
University of Tasmania
http://www.utas.edu.au/dicotkey/dicotkey/MYRTS/sEucalyptus_gunnii.htm

Eucalyptus intertexta R.T.Baker ‘Smooth-barked Coolibah’ Disjunct inland distribution in central Austrlai, including mid North and Flinders Ranges.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2889460
SASeedbank http://saseedbank.com.au/species_information.php?rid=1830

Eucalyptus leucoxylon F.Muell. ‘Blue Gum’ Native to South Australia and Victoria, including study area

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2909698
SA State Flora http://www.stateflora.sa.gov.au/about-us/latest-articles/blue-gum

Eucalyptus microcarpa (Maiden) Maiden. ‘Grey Box’ Native to South Australia (including study area), Victoria and Queensland and New South west of the Great Dividing Range.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2904197
SASeedbank http://saseedbank.com.au/species_information.php?rid=1844

Eucalyptus utilis Brooker & Hooper. ‘Coastal Moort’ Native to Western Australia

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2921212
Florabase https://florabase.dpaw.wa.gov.au/browse/profile/18085

Eucalyptus urophylla S.T. Blake Native to the Indonesian Archipelago and Timor.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/name/apni/119689

Eucalyptus oleosa F.Muell. ex Miq. ‘Red Mallee’ Range extends from Western Australia to Victoria, including study area in South Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/instance/apni/954210
SASeedbank http://saseedbank.com.au/species_information.php?rid=1849

Eucalyptus. piperita Sm. ‘Sydney Peppermint’ Native to New South Wales

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/5323820
Royal Botanic Gardens, Sydney http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Eucalyptus~piperita

Eucalyptus platypus var. heterophylla Blakely ‘Western Moort Native to Western Australia.

Florabase https://florabase.dpaw.wa.gov.au/browse/profile/12071

Eucalyptus platypus var. platypus Hook. subsp. ‘Moort’ Native to Western Australia.

Atlas of Living Australia

http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2904783

Eucalyptus porosa F.Muell. ex Miq. 'Black Mallee Box' Native to South Australia, including study area, and western Victoria and New South Wales.

Atlas of Living Australia

http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2914912

SASeedbank http://saseedbank.com.au/species_information.php?rid=1865

Eucalyptus preissiana Schauer. 'Bell-fruited Mallee' Native to Western Australia.

Atlas of Living Australia

http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2909893

Florabase https://florabase.dpaw.wa.gov.au/browse/profile/5751

Eucalyptus socialis F.Muell. ex Miq. 'Summer Red Mallee' Ranges from inland New South Wales, Victoira, South Australia (including the study) to central Western Australia.

Atlas of Living Australya

http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2914882

SASeedbank http://saseedbank.com.au/species_information.php?rid=1871

Eucalyptus spathulata Hook. 'Swamp Mallee' Native to Western Australia.

Atlas of Living Australia.

http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2912910

Florabank

http://www.florabank.org.au/lucid/key/species%20navigator/media/html/Eucalyptus_spathulata.htm

Eucalyptus tetrapleura L.A.S.Johnson. ‘Square-fruited Ironbark’ Endemic to northern coast of NSW.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2918580

Eucalyptua torquata Luehm. ‘Coral Gum’ Native to Western Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2889289
Florabase https://florabase.dpaw.wa.gov.au/browse/profile/5792

Eucalpytus woodwardii Maiden. ‘Lemon-flowered Gum’ Native to Western Australia

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2886155
Florabase https://florabase.dpaw.wa.gov.au/browse/profile/5799

Eremophila longifolia (R.Br.) F.Muell. DC. ‘Berrigan’ Native to Australia and widespread.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2902046
eFLoraSA http://www.flora.sa.gov.au/cgi-bin/speciesfacts_display.cgi?form=speciesfacts&family=&genus=Eremophila&species=longifolia&iname=&submit=Display

Grevillea acanthifolia A.Cunn. ‘Acanthus-leaved Grevillea’ Native to New South Wales

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2891108

Royal Botanic Gardens Sydney http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Grevillea~acanthifolia

Grevillea robusta A.Cunn. ex. R.Br. ‘Silky Oak’ Native to coastal eastern Australia

Atlas of Living Australia
https://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2918082

Fraxinus angustifolia subsp. ***angustifolia (Vahl) Wesm. ‘Desert Ash’ Native in western Europe south of the Low Countires and in the Mahgreb.***.

Kew Botanic Gardens.
http://wfo.kew.org/taxon/urn:kew.org:wcs:taxon:369667;jsessionid=4F2FA5A3B3C5EF4A98D24211ADC30092.kppapp01

Atlas of Living Australia.
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2893549

Fraxinus excelsior L. ‘Common Ash’ Native to much of Europe, extending from the British Isles to the Caucasus Mountains.

Kew Botanic Gardens
http://www.kew.org/science-conservation/plants-fungi/fraxinus-excelsior-european-ash

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2905302

Indiofera australia Wiild*.* ‘Austral Indigo’ Widespread in the southern part of Australia, including the mid North and Flinders Ranges.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2899160
SASeedbak http://saseedbank.com.au/species_information.php?rid=2389

Jacaranda mimosifolia D. Don. ‘Jacaranda’ Native to southern Bolivia and NW Argentina.

Missouri Botanic Gardens
http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a873

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2911572

Koelreuteria paniculata Laxm. ‘Golden Rain Tree’ Native to eastern Asia.

Missouri Botanic Gardens
http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a550

Atlas of Living Australia
http://bie.ala.org.au/species/ALA_Koelreuteria_paniculata

Lagunaria patersonia (Andrews) G. Don. ‘Norfolk Island Hibiscus’ Endemic to Norfolk and Lord Hows Islands.

Atlas of Living Australia.
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2907714

Liquidambar styraciflua L. ‘American Sweetgum’ Native to North America.

Missouri Botanic Gardens
http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=c116

Malus pumila Mill. ‘Apple’ Global distribution, originally central Asia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2909635

Melaleica gibbosa Labill. ‘Slender Honey-myrtle’ Coastal distribution extending from the Eyre Peninusula through Victoria to eastern Tasmania.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2917016
SAseedbank http://saseedbank.com.au/species_information.php?rid=2876

Melaleuca halmaturorum F.Muell. ex Miq. ‘Salt Paperbark’ Range disjunct including Western Australia and coastal South Australia, including parts of the mid North.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2900003
SASeedbank

Melaleuca lanceolata Otto ‘Dryland Tea-tree or Moonah’ Mainly southern distribution from Western Australia to central Victoria, including the mid North.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2891374
SASeedbank http://saseedbank.com.au/species_information.php?rid=2881

Melaleuca uncinata R.Br. ‘Broom Honey-myrtle’ Native to southern Australia.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/instance/apni/896709
SASeedbank http://saseedbank.com.au/species_information.php?rid=2891

Melia azedarach L. ‘Umbrella Tree’ Native range from Australia to Indomalaya.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2894326

Picea orientalis L. (Peterem.) ‘Oriental Spruce’ Native to Asia.

Kew Botanic Gardens http://www.theplantlist.org/tpl/record/kew-25623

Pinus halepensis Mill. ‘Aleppo Pine’ Native to the Mediterranean littoral and islands

IUCN Red List http://www.iucnredlist.org/details/42366/0
SASeedbank http://saseedbank.com.au/species_information.php?rid=3366

Pinus radiata D.Don ‘Monterrey Pine’ Native to central Californian coast. Introduced to eastern and southern Australia as a timber tree.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2906641

Pittosporum angustifolium Lodd. ‘Native Apricot’ *Native to inland Australia, including study area*

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/7744138
SASeedbank http://saseedbank.com.au/species_information.php?rid=39

Platanus orientalis L. ‘Oriental Plane’ Original range Eurasia east of the Balkans. Now widely planted.

Kew Botanic Gardens http://www.kew.org/science-conservation/plants-fungi/platanus-orientalis-oriental-plane

Populus deltoidies Bartr. ex Marsh ‘Eastern Cottonwood’ Native to eastern and central United States.

USDA https://www.fs.fed.us/database/feis/plants/tree/popdel/all.html

Populus nigra L. var. ***italica*** du Roi. ‘Lombardy Poplar’ Native to Meditteranean Europe and North Africa.

CABI http://www.cabi.org/isc/datasheet/43535

Prunus L. cultivar. “Flowering Cherries’ Original range Eurasia, but widely cultivated.

Atlas of Living Australia.http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2916347

Pyrus communis L. ‘Common pear’ Native to southern and eastern Europe and western Asia. Widely grown.

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2910789
Quercus palustris Münchh.1770 ‘Pin Oak’ Native to eastern United States.

Missouri Botanic Garden
http://www.missouribotanicalgarden.org/PlantFinder/PlantFinderDetails.aspx?kempercode=a904

Quercus robur L. “English Oak’ Native to UK
Kew Botanic Gardens. *http://www.kew.org/science-conservation/plants-fungi/quercus-robur-english-oak http://www.theplantlist.org/tpl1.1/record/kew-174075*

Rhamnus alaternus L. ‘Italian Buckthorn’ Native to the Mediterranean.

USDA https://plants.usda.gov/core/profile?symbol=RHAL12

Salix fragilis L. ‘Crack Willow’ Native to Europe and western Asia.

Missouri Botanic Garden http://www.tropicos.org/Name/100372115

Salix matsudana Koidz. ‘Corkscrew Willow’ Native to northeast China. Includes the twisted leaf variety known as Hankow or Curly Willow.

Flora of China
http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=200005909

Schinus molle L. ‘Peppercorn tree’ Native to South America, extending from Peru through Brazil, to northern Argentina and Chile. Widespread in the study area. A favourite climbing tree of one of my helpful plant identifiers — John Choate – when he was a boy!

Missouri Botanic Garden
http://www.missouribotanicalgarden.org/plantfinder/plantfindersearch.aspx

Atlas of Living Australia
http://bie.ala.org.au/species/http://id.biodiversity.org.au/node/apni/2912800

Ulmus procera Salisb. ‘Common Elm’ Native to southern and western Europe
Kew Botanic Gardens. http://www.theplantlist.org/tpl/record/kew-2448825

Genus listing

Abies Mill. Firs. Native to North and Central America, Eurasia and North Africa.48-56 species.

Acacia Martius (1829). Acacias and Wattles. Native to Australia and Africa, More tha 980 species.

Callistemon R.Br. Bottlebrushes. Endemic to Australia Approximately 50 species.

Casuarina l. Native to Australia, Indian Subcontinent, Southeast Asia and western Pacific. 17 species.

Eucalyptus. L'Hér. Gums, Mallees and Stringybarks. Native to Australia, Papua New Guines and parts of Indonesia. >700 species.

Fagus L. Beeches. Native to temperate Eurasia and North America. 11 species

Larix Phillp Miller Larches. Boreal distribution. 10-14 species.

Melaleuca L nom. cons. Melaleucas. Mostly native to Australia, but a few species are endemic to or range extends to Tasmania, Lord Howe Island, New Caledonia, Papua new Guinea and in south east Asia to Myanmar. 290 species (30 known as Callistemons, see separate listing above)

Tilia L. Limes, Lindens or Basswoods. Native to Europe and eastern North America, 30 species.

Appendix 4.2 Description of lichens found in study area.

Xanthoria parietina

X. parietina has a global distribution, the species is known from Australia, Pacific Islands, Antarctica, Africa, Europe, South America, North and Central America (Lindblom & Ekman, 2006).

It grows on a wide variety of substrates. In this study area it was the most frequently occurring epiphytic lichen, but it was also seem growing on paving stones, rocks and walls. It has been found growing on siliceous rocks at coastal maritime sites (Amstrong, 1991). He added that the samples which were taken from maritime and inland sites did not differ significantly in their calcium and magnesium contents, but the thalli of *X. parietina* cannot grow when transplanted from the maritime to inland sites.

According to Joshi *et al.* (2009) *X. parietina* is characterized by foliose, small thalli often coalescing with other thalli to cover large regions. They are appressed to somewhat acceding and can be smooth, wrinkled or concave, The colour is generally described as orange to yellow (but it ranges from bronze yellow in exposed conditions to a French grey in shady conditions) The lobe attached by hapters, soredia and isidia are absent, there are numerous large (1-3mm diameter) apothecia with broadly ellipsoid spores (13~16 × 6.5~8µm) and ellipsoid conidia.

When tested by chemistry they show the following spot test reactions: thallus and epihymenium K+ purple, C-, P-. Secondary metabolites: parietin (major), fallacinal, emodin, teloschistin and parietinic acid. Chemosyndrome C.

A study in Turkey (Demiraya *et al.*, 2012) selected *X. parietina* as a biomonitoring organism due to its common occurrence in the urban regions and high tolerance to atmospheric pollution. In France (Agnan *et al.*, 2013), selected *X. parietina* to investigate past (sourced from a herbarium) and present-day trace metal pollution in south-east France (close to Albi). ly for contemporary data.

According to Joshi *et al.* (2009) *X. parietina* is often confused with *X. polycarpa* (Hoffm.) Rieber and *Xanthoria elegans* (Link) Th. Fr. The smaller cushion-like thallus with short and narrow convex lobes of *X. polycarpa* separates it from *X. parietina*, while tightly adnate, narrow, convex lobes and deep red colour of *X. elegans* separates it from *X. parietina*. *X. dissectula* S. Y. Kondr. & Kärnefelt, another related species, differs in having smaller and more closely appressed thallus, more irregularly-shaped, horizontally-oriented and dissected lobes, rhizinate lobe margins, pseudoprosoplectenchymatous true excipulum and much smaller spores. Raised thallus, rhizines as attachment organs, apothecia ± rhizinate, smaller spores and bacilliform conidia separates both *X. alfredi* S. Y. Kondr. & Poelt and *X. aphrodites* Kalb, Poelt & S. Y. Kondr. from it.

Caloplaca holocarpa

C. holocarpa has a disjunct distribution being found in Scandinavia, central European Russia, southern Europe and Australia. It is recently been shown that *C. holocarpa* is in fact of small group of species which overlap and the species are easily confused at the identification stage. All of them have a reduced thallus and conspicuous yellow, orange or red apothecia. The species are *C. halocarpa, C. pyracea* and *C. vitellinula* (Arup, 2009), and if must be identified using the apothecial characters there is great difficulty in separating them. In reality these species can only be genetically defined using the nrITS DNA gene. According to Vondrak *et al.* (2012) the members of the family *Teloschistaceae* belong to the *C. holocarpa* group. Two species new to Russia were recently discovered: *C. atroflava Turner)* Mong. *s.l.* and *C. soralifera* Vondrak Hrounzek.

Physcia aipolia

P. aipolia occurs in Australia and New Zealand. According to Galloway and Moberg (2005) *P. aipolia* is folliicolus epiphytic lichens, however, it can be seen on many other substrates, such as on rocks or on concrete. In this study it occurred as a corticolous lichen. Its upper surface varies from white to pale green, green-grey and dark-grey. It is not darken when moistened.

Lecidella elaeochroma

There have been very few references to *L. elaeochroma*. Irish lichens (2017) indicated that is a corticolous lichen and commonly grows on smooth-barked trees and fences. The species is smooth to slightly granular. The thallus is light-grey to yellowish-grey and is surrounded by a black prothallus. The spores are simple, thick-walled, 10-17 x 6-9µm. In chemical spots tests it is normally K+ yellow, C+ orange, KC+ yellow, P-, UV+ orange.

Chrysothrix xanthina

There is also a lack of information on detailed descriptions this species. However, a number of webpages showing the photos, especially the genus of *Chrysothrix.*

REFERENCES

ABC Radio Hobart. (2017). *Coral lichen (Cladia retipora): 2012*. Retrieved from http://www.abc.net.au/local/photos/2013/01/25/3676874.htm

Agnan, Y., Séjalon-Delmas, N., & Probst, A. (2013). Comparing early twentieth century and present-day atmospheric pollution in SW France: A story of lichens. *Environmental Pollution, 172*, 139-148.

Ajami, M., & Khormali, F. (2011). Role of lichen covers in conserving loess-derived soils in Northern Golestan province: Physico-chemical and micromorphological approach. *Journal of Science and Technology of Agriculture and Natural Resources, Water and Soil Science, 15*, 91-100.

Alexander, R. W., & Calvo, A. (1990). The influence of lichens on slope processes in some Spanish badlands. In Thornes, J.B. (ed) *Vegetation and Erosion,* Wiley, Chichester. 385-398.

Almborn, O. (1948). Distribution and ecology of some South Scandinavian lichens. *Botaniska Notiser, Supplement, 1*, 1-254.

Altman, D. G., & Bland, J. M. (1995). Statistics notes: the normal distribution. *British Medical Journal, 310*, 298.

Amo de Paz, G., & Burgaz, A. R. (2009). Environmental factors and diversity of epiphytic communities on the trunk of the Mediterranean beech forest in Hayedo de Montejo (Madrid, Spain). *Cryptogamie, Mycologie, 30*, 85-97.

Amstrong, R. A. (1991). The influence of calcium and magnesium on the growth of the lichens *Parmelia saxatilis* and *Xanthoria parietina* on slate substrates. *Environmental and Experimental Botany, 30*, 51-57.

Anthony, P. A., Holtum, J. A. M., & Jackes, B. R. (2002). Shade acclimation of rainforest leaves to colonization by lichens. *Functional Ecology, 16*, 808-816.

Aptroot, A. (1997). Lichen biodiversity in Papua New Guinea, with the report of 173 species on one tree. *Bibliology Lichenolonogy, 68*, 203-213.

Aptroot, A., & van Herk, C. M. (2007). Further evidence of the effects of global warming on lichens, particularly those with *Trentepohlia phycobionts*. *Environmental Pollution, 146*(2), 293-298.

Armesto, J. J., & Contreras, L. C. (1977). Saxicolous lichen communities: nonequilibrium system? *The American Naturalist, 118*, 597-604.

Armstrong, R. A. (1984). The influence of bird droppings and uric acid on the radial growth of five species of saxicolous lichens. *Environmental and Experimental Botany, 24*, 95-99.

Armstrong, R. A. (1997). Are metal ions accumulated by saxicolous lichens growing in a rural environment? *Environmental and Experimental Botany, 38*, 73-79.

Armstrong, R. A., & Bradwell, T. (2011). Growth of foliose lichens: a review. *Symbiosis, 53*(1), 1-16.

Arup, U. (2009). The Caloplaca holocarpa group in the Nordic countries, except Iceland. *The Lichenologist, 41*(2), 111-130.

Asta, J., Erhardt, W., Ferretti, M. F., F., Kirschbaum, U., Nimis, P. L., Purvis, O. W., . . . Wirth, V. (2002). Mapping lichen diversity as an indicator of environmental quality. *Monitoring with Lichens - Monitoring Lichens, 7*, 273-279.

Asta, J., Erhardt, W., Ferretti, M., Fornasier, F., Kirschbaum, U., Nimis, P. L., . . . Wirth, V. (2008). European guidelines for mapping lichen diversity as an indicator of environmental stress. *The British Lichen Society, London*, 1-20.

Australian institute of Criminology. (2014). Illegal native vegetation clearance. Australian Government, Australian Institute of Criminology, Canberra. Retrieved from http://www.aic.gov.au/publications/current%20series/rpp/100-120/rpp109/09.html

Balhannah Nurseries. (2017). Flowering Ornamentals. Retrieved from http://balhannahnurseries.com.au/catalogue/flowering-ornamentals-2/

Bary, A. D. (1866). *Morphologie und Physiologie der Pilze, Flechten und Myxomyceten*: W. Engelmann, Leipzig.

Beesley, C. A., Frost, A. J., & Zajaczowski, J. (2009). A comparison of the BAWAP and SILP spatially interpolated daily rainfall datasets. Proceedings 18th World IMACS/MODSIM Congress, Cairns, Australia 13-17th July 2009. Retrieved from mssanz.org.au/modsim09

Belinchón, R., Yahr, R., & Ellis, C. J. (2014). Interactions among species with contrasting dispersal modes explain distributions for epiphytic lichens. *Ecography, 37*, 1-7.

Benning, J. (2012-2017). Leaf-ID.com. Retrieved from http://www.leaf-id.com

Benson, J. S. (1991). The effect of 200 years of European settlement on the vegetation and flora of New South Wales. *Cunninghamia, 2*, 343-370.

Berg, A., Ehnstrom, B., Gustafsson, L., Hallingback, T., Jonsell, M., & Weslien, J. (1994). Threatened plant, animal, and fungus species in Swedish forests: Distribution and habitat associations. *Conservation Biology, 8*, 718-731.

Bergamini, A., Scheidegger, C., Stofer, S., Carvalho, P., Davey, S., Dietrich, M., . . . Watt, A. (2005). Performance of macrolichens and lichen genera as indicators of lichen species richness and composition. *Conservation Biology, 19*, 1051-1062.

Bjelland, T. (2003). The influence of environmental factors on the spatial distribution of saxicolous lichens in a Norwegian coastal community. *Journal of Vegetation Science, 14*, 525-534.

Bolliger, J., Bergamini, A., Stofer, S., Kienast, F., & Scheidegger, C. (2007).

Predicting the potential spatial distributions of epiphytic lichen species at the landscape scale. *The Lichenologist, 39*, 279-291.

Boom, P. V. D. (1996). A site with foliicolous lichens in Belgium. *Belgian Journal of Botany, 129*, 19-23.

Boudreault, C., Gauthier, S., & Bergeron, Y. (2000). Epiphytic lichens and bryophytes on *Populus tremuloides* along a chronosequence in the southwestern boreal forest of Quebec, Canada. *The Bryologist, 103*, 725-738.

Brockman, C. F., & Marrilees, R. (2002). *Trees of North America: A Guide to Field Identification*: St. Martin's Press, New York.

Brodo, I. M., Duran, S., & Sharnoff, S. (2001). *Lichens of North America*: Yale University Press, New Haven, Connecticut.

Brown, M. J. (1988). *Distribution and conservation status of King Billy Pine*: Forestry Commission, Hobart, Tasmania.

Brown, M. J., Jarman, S. J., & Kantvilas, G. (1994). Conservation and reservation of non-vascular plants in Tasmania, with special reference to lichens. *Biodiversity and Conservation, 3*, 263-278.

Burgaz, A. R., Fuertes, E., & Escudero, A. (1994a). Epiphytic mature communities in Mediterranean Spain. *Botanical Journal of the Linnean Society, 115*, 35-47.

Burgaz, A. R., Fuertes, E., & Escudero, A. (1994b). Ecology of cryptogamic epiphytes and their communities in deciduous forest in Mediterranean Spain. *Vegetation, 112*, 73-86.

Cáceres, M. E. S., Lücking, R., & Rambold, G. (2007). Phorophyte specificity and environmental parameters versus stochasticity as determinants for species composition of corticolous crustose lichen communities in the Atlantic rain forest of northeastern Brazil. *Mycological Progress, 6*(3), 117-136.

Cameron, R. P., Neily, T., & Clayden, S. R. (2011). Distribution prediction model for Erioderma mollissimum in Atlantic Canada. *The Bryologist, 114*(1), 231-238.

Chapman, A. D. (2009). *Numbers of living species in Australia and the World (2nd ed.)*. Retrieved from https://www.environment.gov.au/system/files/pages/2ee3f4a1-f130-465b-9c7a-79373680a067/files/07-nlsaw-fungi.pdf

Chen, J., Blume, H. P., & Beyer, L. (2000). Weathering of rocks induced by lichen colonization - a review. *Catena, 39*, 121-146.

Cislaghi, C., & Nimis, P. L. (1997). Lichens, air pollution and lung cancer. *Nature, 387*, 463-464.

Clarke, G. M. (1994). *Statistics and experimental design: An introduction for biologists and biochmists* (3rd edn ed.): Hodder & Stoughton, London.

Cobanoglu, G., & Sevgi, O. (2009). Analysis of the distribution of epiphytic lichens on *Cedrus libani* in Elmali Research Forest (Antalya, Turkey). *Journal of Environmental Biology, 30*(2), 205-212.

Costermanns, L. (2009). *Native Trees and Shrubs of South-Eastern Australia. CSIRO Publishing*: New Holland Publishers, Chatsworth, NSW.

Cremer, K. W., & Mount, A. B. (1965). Early stages of plant succession following the complete felling and burning of *Eucalyptus regnans* forest in the Florentine Valley, Tasmania. *Australian Journal of Botany, 13*, 303-322.

Crisan, F. (2010). Contributions to the study of the corticolous lichen vegetation of the Padurea Craiului mountains (Bihor department, Romania). *Studia Universitatis Vasile Goldis Seria Stiintele Vietii (Life Sciences Series), 20*(3), 71-76.

CSIRO. (1999). *Flora of Australia, Introduction* (Vol. 1): 2nd edn., ABRS/CSIRO, Melbourne.

CSIRO. (2015). New climate change projections for Australia. Retrieved from https://www.csiro.au/en/News/News-releases/2015/New-climate-change-projections-for-Australia

Culberson, W. L. (1955). The corticolous communities of lichens and bryophytes in the upland forests of Northern Wisconsin. *Ecological Monographs, 25*, 215-231.

Davenport, E. C., & Al-Sunhurry, N. A. (1991). Phi/Phimax: Review and Synthesis. *Educational and Psychological Measurement, 51*(4), 821-828.

Demiraya, A. D., Yolcubala, I., Akyola, N. H., & Cobanoglu, G. (2012). Biomonitoring of airborne metals using the lichen *Xanthoria parietina* in Kocaeli Province, Turkey. *Ecological Indicators, 18*, 632–643.

Department for Environment and Heritage. (2017). *No Species Lost - (A Nature Conservation Strategy for South Australia 2007-2017)*. Department for Environment and Heritage, South Australia.

DEWNR. (n.d.). Clearance Guidelines. Retrieved from https://www.environment.sa.gov.au/managing-natural-resources/native-vegetation/clearing/clearance-guidelines

Dittrich, S., Hauck, M., Schweigatz, D., Dörfler, I., Hühne, R., Bade, C., . . . Leuschner, C. (2013). Separating forest continuity from tree age effects on plant diversity in the ground and epiphyte vegetation of a Central European mountain spruce forest. *Flora, 208*, 238-246.

Duncan, D., & Dalton, P. J. (1982). Recolonisation of bryophytes following fire. *Journal of Bryology, 12*, 53-63.

Duncan, F., & Brown, M. J. (1985). *Dry sclerophyll vegetation in Tasmania: Extent and conservation status of the communities. Wildlife Division Technical report*. Retrieved from National Parks and Wildlife Service, Tasmania:

Echeverria, C., Coomes, D., Salas, J., Rey-Benayas, J. M., Lara, A., & Newton, A. (2006). Rapid deforestation and fragmentation of Chilean Temperate Forests. *Biological Conservation, 130*, 481-494.

Eldridge, D. J. (1999). Distribution and floristics of moss- and lichen-dominated soil crusts in a patterned *Callitris glaucophylla* woodland in eastern Australia. *Acta Oecologica, 20*, 1959-1970.

Ellenberg, H., & Mueller-Dombois, D. (1974). *Aims and Methods of Vegetation Ecology*: John Wiley and Sons, New York.

Elliott, A. C., & Woodward, W. A. (2007). *Statiscal analysis quick reference guidebook with SPSS examples*: Sage Publications, London.

Ellis, C. J., Coppins, B. J., & Dawson, T. P. (2007). Predicted response of the lichen epiphyte *Lecanora populicola* to climate change scenarios in clean-air regions of Northern Britain. *Biological Conservation, 135*, 396-404.

Ellis, C. J., Coppins, B. J., Dawson, T. P., & Seaward, M. R. D. (2007). Response of British lichens to climate change scenarios: Trends and uncertainties in the projected impact for contrasting biogeographic groups. *Biological Conservation, 140*, 217-235.

Ellis, C. J., Eaton, S., Theodoropoulos, M., Coppins, B. J., Seaward, M. R. D., & Simkin, C. (2014). Response of epiphytic lichens to 21st Century climate change and tree disease scenarios. *Biological Conservation, 180*, 153-164.

Ennos, R. (2000). *Statistical and Data Handling Skills in Biology*. Harlow, England: Prentice Hall.

Eppinger, M. (2006). *Field guide to trees and shrubs of Britain and Europe*: New Holland Publishers, London.

Esseen, P. A., Renhorn, K. E., & Pettersson, R. B. (1996). Epiphytic lichen biomass in managed and old-growth boreal forests: effect of branch quality. *Ecological Applications, 6*, 228-238.

Esslinger, T. L. (2006). A cummulative checklist for the lichen-forming, lichenicolous, and allied fungi of the continental United States and Canada. Retrieved from https://www.ndsu.edu/pubweb/~esslinge/chcklst/chcklst7.htm

Evju, M., & Bruteig, I. E. (2013). Lichen community change over a 15-year time period: effects of climate and pollution. *The Lichenologist, 45*(01), 35-50.

Fanning, E., Ely, J. S., Lumbsch, H. T., & Keller, H. W. (2007). Vertical distribution of lichen growth forms in tree canopies of Great Smoky Mountains national park. *Southeastern Naturalist, 1*, 83-88.

Farkas, E., Elix, J. A., & Flakus, A. (2012). *Calopadia erythrocephala,* a new foliicolous lichenized fungus from Brazil. *The Lichenologist, 44*, 395-399.

Filson, R. B., & Rogers, R. W. (1979). *Lichens of South Australia*: Government Printer, Adelaide, South Australia.

Fleming. (2017). Plant Search. Retrieved from http://www.flemings.com.au

Forestry Commission. (1989). *Forest Pratices Code*: Forestry Commission, Hobart, Tasmania.

Fritz, O., Niklasson, M., & Churski, M. (2009). Tree age is a key factor for the conservation of epiphytic lichens and bryophytes in beech forests. *Applied Vegetation Science, 12*, 93-106.

Galloway, D. J. (1985). *Flora of New Zealand lichens*: Government Printer, Wellington, New Zealand.

Galloway, D. J., & Moberg, R. (2005). The lichen genus *Physcia* (Schreb.) Michx (*Physciaceae: Ascomycota*) in New Zealand. *Tuhinga, 16*, 59-91.

Galun, M. (1998). *CRC handbook of lichenology*: CRC Press, Boca Raton, Florida.

Gamlin, L. (1988). Sweden's factory forests. *New Scientist, 1957*, 41-44.

Garrido-Benavent, I., Llop, E., & GóMez-Bolea, A. (2015). The effect of agriculture management and fire on epiphytic lichens on holm oak trees in the eastern Iberian Peninsula. *The Lichenologist, 47*, 59-68.

Ghasemi, A., & Zahediasl, S. (2012). Normality tests for statistical analysis: A guide for non-statisticians. *International Journal of Endocrinology Metabolism, 10*, 486-489.

Giordani, P. (2007). Is the diversity of epiphytic lichens a reliable indicator of air pollution? A case study from Italy. *Environmental Pollution, 146*, 317-323.

Giordani, P., & Incerti, G. (2008). The influence of climate on the distribution of lichens: a case study in a borderline area (Liguria, NW Italy). *Plant Ecology, 195*, 257-272.

Glew, K. (2000). Lichen conservation: Rare lichens found in Washington state. *The American Journal of Botany, 87*, 8.

Government of Australia. (2016). *State of the Environment Report 2016*: Australian Government Department of the Environment and Energy, Canberra.

Government of South Australia. (2016). South Australia Native Vegetation Act (1991). Version 4.7.2016. Retrieved from https://www.legislation.sa.gov.au/LZ/C/A/NATIVE%20VEGETATION%20ACT%201991/CURRENT/1991.16.UN.PDF

Government of South Australia. (2017). South Australia National Parks and Wildlife Act (1972) Version 15.32017. Retrieved from https://www.legislation.sa.gov.au/LZ/C/A/NATIONAL%20PARKS%20AND%20WILDLIFE%20ACT%201972/CURRENT/1972.56.UN.PDF

Gradstein, R., Hietz, P., Lücking, R., Sipman, H. J. M., Vester, H., Wolf, J., &

Gardette, E. (1996). How to sample the epiphytic diversity of tropical rain forests. *Ecotropica, 2*(59-72).

Grube, M. (2010). Foliicolous lichens. *The Bryologist, 113*(1), 224-226.

Guevara, M. L. D., Gozalo, B., Raggio, J., Lafuente, A., Prieto, M., & Maestre, F. T. (2018). Warming reduces the cover, richness and evenness of lichen-dominated biocrusts but promotes moss growth: insights from an 8 yr experiment. *New Phytologist*.

Hale, M. E. (1974). *The biology of lichens*: Elsevier, New York.

Hale, M. E. (1983). *The biology of lichens*: Edward Arnold, London.

Haucka, M., Dulamsuren, C., & Mühlenberg, M. (2007). Lichen diversity on steppe slopes in the northern Mongolian mountain taiga and its dependence on microclimate. *Flora, 202*, 530-546.

Hawksworth, D. L., & Hill, D. J. (1984). *The lichen-forming fungi*: Blackie, Glasgow and London.

Heathcote, R. L. (2004). Goyder's Line: a line for all seasons? *South Australian Geographical Journal, 103*, 73-94.

Hedenås, H., Bolyukh, V. O., & Jonsson, B. G. (2003). Spatial distribution of epiphytes on *Populus tremula* in relation to dispersal mode. *Journal of Vegetation Science, 14*(2), 233-242. doi:10.1111/j.1654-1103.2003.tb02148.x

Hensel, S. T. (1902). Lichens on Rocks. *Science, 16*, 593.

Henssen, A., & Jahns, H. M. (1974). *Lichens*: Georg Thieme, Stuttgart.

Henssen, A., & Kantvilas, G. (1985). *Wawea fruticulosa,* a new genus and species from the Southern Hemisphere. *The Lichennologist, 17*, 85-97.

Hertel, H., & Andreev, M. P. (2003). On some saxicolous lecideoid lichens of the Beringian Region and adjacent areas of Eastern Siberia and the Russian Far East. *The Bryologist, 106*(4), 539-551.

Herzig, R., Liebendorfer, L., Urech, M., Amman, K., Cuecheva, M., & Landolt, W. (1989). Passive biomonitoring with lichens as a part of an integrated biological measuring system for monitoring air pollution in Switzerland. *International Journal of Environmental Analytical Chemistry, 35*, 43-57.

Hickling, R., Roy, D. B., Hill, J. K., & Thomas, C. D. (2005). A northward shift of range margins in British Odonata. *Global Change Biology, 11*, 502-506.

Hilmo, O. (1994). Distribution and succession of epiphytic lichens on *Picea abies* branches in a boreal forest, Central Norway. *The Lichenologist, 26*, 149-169.

Hur, J. S., Harada, H., Lim, K. M., Lee, S. M., Le, V. V., Oh, S. O., & Koh, Y. J. (2004). Stimulation of soil microbial activity by lichen colonization in an abandoned coalmine waste dump soil. *Lichenology, 3*(1), 1-9.

Hur, J. S., Harada, H., Oh, S. O., Lim, K. M., Kang, E. S., Lee, S. M., . . . Koh, Y. J. (2004). Distribution of lichen flora in Korea. *The Journal of Microbiology, 42*, 163-167.

Insarov, G., & Insarova, I. (1996). Assement of lichen sensitivity to climate change. *Israel Journal of Plant Sciences, 44*, 309-334.

Insarov, G., & Schroeter, B. (2002). Lichen Monitoring and Climate Change. *Monitoring with Lichens - Monitoring Lichens, 7*, 183-201.

Insarov, G. E., Semenov, S. M., & Insarova, I. D. (1999). A system to monitor climate change with epilithic lichens. *Environmental Monitoring and Assessment, 55*(2), 279-298.

International Union for Conservation of Nature. (2017). The IUCN red list of threatened species. Retrieved from http://www.iucnredlist.org/static/categories_criteria_3_1

Irish lichens. (2017). Retrieved from http://www.irishlichens.ie/pages-lichen/l-200.html

James, P. W., Hawksworth, D. L., & Rose, F. (1977). *Lichen communities in the Bristish Isles: a preliminary conspectus*: Academic Press, London.

Jarman, S. J., & Kantvilas, G. (2001). Bryophytes and lichens at the Warra LTER site. II. Understorey habitats in Eucalyptus obliqua wet sclerophyll forest. *Tasforests, 13*, 217-243.

Jarman, S. J., Brown, M. J., & Kantvilas, G. (1984). *Rainforests in Tasmania*: National Parks and Wildlife Service, Hobart, Tasmania.

Jarman, S. J., Kantvilas, G., & Brown, M. J. (1988). *Buttongrass moorland in Tasmania, Research report no. 2. Tasmanian Forest Research Council Inc. Hobart*. Retrieved from

Jarman, S. J., Kantvilas, G., & Brown, M. J. (1994). Phytosociological studies in Tasmanian cool temperate rainforest. *Phytocoenologia, 22*, 355-390.

Jayalal, U., Oh, S. O., Lücking, R., Joshi, S., Kim, J. A., Park, J. S., & Hur, J. S. (2013). Contributions to the foliicolous lichens flora of South Korea. *Mycobiology, 41*(4), 202-209.

Johansson, P., Rydin, H., & Thor, G. (2007). Tree age relationships with epiphytic lichen diversity and lichen life history traits on ash in southern Sweden. *Ecoscience, 14*, 81-91.

Johnson, K. (2015). The Port Augusta Power Station's history. The Transcontinental (Port Augusta), June 17th 2015. .

Jönsson, M. T., Ruete, A., Kellner, O., Gunnarsson, U., & Snäll, T. (2016). Will forest conservation areas protect functionally important diversity of fungi and lichens over time? *Biodiversity and Conservation*. Retrieved from https://link.springer.com/article/10.1007/s10531-015-1035-0

Joshi, Y., Wang, X. Y., Lee, Y. M., Byun, B. K., Koh, Y. J., & Hur, J. S. (2009). Notes on some new records of macro- and micro-lichens from Korea. *Mycobiology, 37*, 197-202.

Kantvilas, G. (1993). *Bacidia albidoplumbea* (lichenised Ascomycotina) and its taxonomic synonyms in Tasmania. *Muelleria, 8*, 43-46.

Kantvilas, G. (2000). Conservation of Tasmanian lichens. *Snow Landscape Reservation, 75*, 357-367.

Kantvilas, G. (2016). Further additions to the lichen genus Ramboldia *(Lecanoraceae)* from Australia. *Muelleria, 34*, 103-109.

Kantvilas, G., & Jarman, S. J. (1988). Lichens of buttongrass *(Gymnoschoenus)* moorland in Tasmania. *Papers and proceedings of the Royal Society of Tasmania, 122*, 1-17.

Kantvilas, G., & Minchin, P. R. (1989). An analysis of epiphytic lichen communities in Tasmania cool temperate rainforest. *Vegetatio, 84*, 99-112.

Kantvilas, G., & Jarman, S. J. (1991). *Lichens and bryophytes of the Tasmanian World Heritage Area. I. Mount Sprent. In Aspects of Tasmanian Botany - A Tribute to Winifred Curtis (R. Banks, S.J. Smith, A.E. Orchard and G. Kantvilas, eds)*: Royal City of Tasmania, Hobart.

Kantvilas, G., & Jarman, S. J. (2004). Lichens and bryophytes on *Eucalyptus obliqua* in Tasmania: Management implications in production forests. *Biological Conservation, 117*, 359-373.

Kantvilas, G., Elix, J. A., & James, P. W. (1992). *Siphulella,* a new lichen genus from southeast Tasmania. *The Bryologist, 95*(186-191), 186-191.

Kermit, T., & Gauslaa, Y. (2001). The vertical gradient of bark pH of twigs and macrolichens in a *Picea abies* canopy not affected by acid rain. *The Lichenologist, 33*(4), 353-359.

Kershaw, K. A. (1985). *Physiological ecology of lichens*: Cambridge University Press, Cambridge.

Khodosovtsev, A. Y., Kondratyuk, S. Y., Makarova, I. I., & Oxner, A. N. (2004). *Handbook of the lichens of Russia. 9. Fuscideaceae, Teloschistaceae* (eds. Andreev M.P., Roms E.G.), Sankt-Peterburg, Nauka.

Kiebacher, T., Keller, C., Scheidegger, C., & Bergamini, A. (2016). Hidden crown jewels: the role of tree crowns for bryophyte and lichen species richness in sycamore maple wooded pastures. *Biodiversity Conservation, 25*, 1605-1624.

Kirkpatrick, J. B. (1983). An iterative method for establishing priorities for the establishment of nature reserves: An example from Tasmania. *Biological Conservation, 25*, 127-134.

Kirkpatrick, J. B., & Harris, R. C. (1995). *The conservation of Tasmanian dry coastal vascular plant communities. Wildlife Scientific Report 95/1. National Parks and Wildlife Service, Hobart*. Retrieved from

Kirkpatrick, J. B., Brown, M. J., & Moseal, A. (1980). *Threatened plants of the Central East Coast*: Tasmanian Conservation Trust, Hobart.

Kirkpatrick, J. B., Peacock, R. J., Cullen, P. J., & Neyland, M. G. (1988). *The wet eucalypt forests of Tasmania*: Tasmanian Conservation Trust.

Kirschbaum, H., & Windisch, U. (1986). Eutrophication and climate change. *Harmful Algae, 14*, 313.

Komposch, H., & Hafellner, J. (1999). List of lichenized fungi so far observed in the tropical lowland rain forest plot Surumoni (Venezuela, Estado Amazonas). *Fritschiana, 19*, 1-10.

Komposch, H., & Hafellner, J. (2000). Diversity and vertical distribution of lichens in a Venezuelan tropical lowland rain forest. *Selbyana, 21*, 11-24.

Komposch, H., & Hafellner, J. (2002). Life form diversity of lichenized fungi in an Amazon lowland rainforest. *Bibliology Lichenology, 82*, 311-326.

Komposch, H., & Hafellner, J. (2003). Species composition of lichen dominated corticolous communities: a lowland rain forest canopy compared to an adjacent shrubland in Venezuela. *Bibliology Lichenology, 86*, 351-367.

Kondratyuk, S. Y. (2008). *Indication of envinronment of Ukraine with lichens ("Scientific Book" Project)*. Kyiv: Naukova dumka.

Kondratyuk, S. Y., Kärnefelt, I., & Thell, A. (2006). New species of *Xanthoria (Teloschistaceae)* from Australia. *Nuytsia, 16*, 63-76.

Kondratyuk, S. Y., Kärnefelt, I., Elix, J. A., & Thell, A. (2007a). Contributions to the Teloschistaceae of Australia in Lichenologische Nebenstunden - Festschrift in honour of Klaus Kalb. A. Frisch, U. Lange & B. Staiger (eds). *Bibliotheca Lichenologica, 96*, 157-174.

Kondratyuk, S. Y., Kärnefelt, I., Elix, J. A., & Thell, A. (2007b). New species of the genus *Caloplaca* in Australia In: Lichenological contributions in honour of David Galloway. I. Kärnefelt & A. Thell (eds.). J. Cramer in der Gebruder Borntraeger Verlagsbuchhandlung. *Bibliotheca Lichenologica, 95*, 341-386.

Kondratyuk, S. Y., Kärnefelt, I., Elix, J. A., & Thell, A. (2009a). Contributions to the Teloschistaceae, with particular reference to the Southern Hemisphere. In: Thell, A., Seaward, M. R. D. & Feurer, T. (eds). Diversity of Lichenology – Anniversary Volume. *Bibliotheca Lichenologica, 100*, 207-282.

Kondratyuk, S. Y., Kärnefelt, I., Elix, J. A., & Thell, A. (2009b). New Caloplaca species from Australia in Biodiversity and ecology of lichens – Liber Amicorum Harrie Sipman. A. Aptroot, M.R.D. Seaward & L.B. Sparrius (eds). *Bibliotheca Lichenologica, 99*, 259-278.

Kondratyuk, S. Y., Kärnefelt, I., Thell, A., & Elix, J. A. (2010). Six new species of Caloplaca (Teloschistaceae, Ascomycota) from Australasia. *Australasian Lichenology, 66*, 30-43.

Kondratyuk, S. Y., Elix, J. A., Kärnefelt, I., & Thell, A. (2011). Four new Caloplaca species with depsidones. In: Bates et al. (eds). Biomonitoring, Ecology, and Systematics of Lichens. *Bibliotheca Lichenologica, 106*, 179-186.

Kondratyuk, S. Y., Elix, J. A., Kärnefelt, I., & Thell, A. (2012). An artificial key to Australian *Caloplaca* species *(Teloschistaceae, Ascomycota)*. *Bibliotheca Lichenologica, 108*, 141-160.

Kondratyuk, S. Y., Elix, J. A., Kärnefelt, I., Galanina, I. A., Yakovchenko, L. S., & Thell, A. (2011). Four new Caloplaca species (Teloschistaceae, Ascomycotina). – Folia Cryptog. *Estonica, 48*, 17-23.

Kricke, R. (2002). *Measuring bark pH*: Kluwer Academic Publishers, Essen, Germany.

Kuusinen, M., & Siitonen, J. (1998). Epiphytic lichen diversity in old-growth and managed *Picea abies* stands in southern Finland. *Journal of Vegetation Science, 9*, 283-292.

Larsen, R. S., Bell, J. N. B., James, P. W., Chimonides, P. J., Rumsey, F. J., Tremper, A., & Purvis, O. W. (2007). Lichen and bryophyte distribution on oak in London in relation to air pollution and bark acidity. *Environmental Pollution, 146*(2), 332-340. doi:http://dx.doi.org/10.1016/j.envpol.2006.03.033

Lättman, H., Milberg, P., Palmer, M. W., & Mattsson, J. E. (2009). Changes in the distributions of epiphytic lichens in southern Sweden using a new statistical method. *Nordic Journal of Botany, 27*, 413-418.

Lázaro, R., Alexander, R. W., & Puigdefabregas, J. (2000). Cover distribution patterns of lichens, annuals and shrubs in the Tabernas Desert, Almería, Spain. In R.W. Alexander and A.C. Millington (eds.) *Vegetation Mapping: from patch to planet,* Wiley, Chichester. In (pp. 19-40).

Lázaro, R., Cantón, Y., Solé-Benet, A., Bevan, J., Alexander, R. W., Sancho, L. G., & Puigdefábregas, J. (2008). The influence of competition between lichen colonization and erosion on the evolution of soil surfaces in the Tabernas badlands (SE Spain) and its landscape effects. *Geomorphology, 102*, 252-266.

doi:10.1016/j.geomorph.2008.05.005

Legrand, I., Asta, J., & Goudard, Y. (1996). Variations in bark acidity and conductivity over the trunk length of silver fir and Norway spruce. *Trees, 11*, 54-58.

Lesmerises, R., Ouellet, J. P., & St-Laurent, M. H. (2011). Assessing terrestrial lichen biomass using ecoforest maps: a suitable approach to plan conservation areas for forest-dwelling caribou. *Canadian Journal of Forest Research, 41*(3), 632-642.

Li, S., Liua, W. Y., & Li, D. W. (2013). Bole epiphytic lichens as potential indicators of environmental change in subtropical forest ecosystems in southwest China. *Ecological Indicators, 29*, 93-104.

Lindblom, L., & Ekman, S. (2006). Genetic variation and population differentiation in the lichen-forming ascomycete *Xanthoria parietina* on the island Storfosna, central Norway. *Molecular Ecology, 15*, 1545–1559.

Linkola, K. (1918). Über die jahrlichen Längenzuwachs einiger Parmelia and Parmeliopsis Arten. *Medd Soc Fauna Flora Fenn, 44*, 153-158.

Looby, C. I., & Treseder, K. K. (2018). Shifts in soil fungi and extracellular enzyme activity with simulated climate change in a tropical montane cloud forest. *Soil Biology and Biochemistry, 117*, 87-96.

Lorenzini, G., Landi, U., Loppi, S., & Nali, C. (2003). Lichen distribution and bioindicator tobacco plants give discordant response: A case study from Italy. *Environmental Monitoring and Assessment, 82*(3), 243-264. doi:10.1023/A:1021990217117

Lücking, R. (2008). Foliicolous lichens as model organisms to study tropical rainforest ecology: background, data, and protocols. *Sauteria, 15*, 335-362.

Lugo-Fuenmayor, G. (2013). Preliminary inventory of corticolous lichens of the

Sierra de San Luis, Venezuela. *Revolution Neotropical Biodiversity, 3*, 98-105.

Lumbsch, T. (2017). One hundred new lichen species described. Retrieved from https://www.fieldmuseum.org/science/blog/one-hundred-new-lichen-species-described

Marini, L., Nascimbene , J., & Luigi Nimis, P. L. (2011). Large-scale patterns of epiphytic lichen species richness: Photobiont-dependent response to climate and forest structure. *Science of the Total Environment, 409*, 4381-4386.

Marsh, J. E., & Timoney, K. P. (2005). How long must northern saxicolous lichens be immersed to form a waterbody trimline? *Wetlands, 25*, 495-499.

May, P. F. (2000). How to collect lichens. *Farlow Herbarium, Harvard University, Cambridge, Massachusetts.* Retrieved from http://www2.huh.harvard.edu/collections/lichens/collecting.html

McCarthy, P. M. (2013). Checklist of the lichens of Australia and its Island Territories. Retrieved from http://www.anbg.gov.au/abrs/lichenlist/itroduction.html

McCormick, N., & Cunningham, J. (1989). Uneven-aged forest management in Tasmania's dry sclerophyll forests. *Tasforests, 1*, 5-12.

McCune, B., Rosentreter, R., Ponzetti, J. M., & Shaw, D. C. (2000). Epiphyte habitats in an old conifer forest in western Washington, USA. *The Bryologist, 103*, 417-427.

McMullin, R. T., Thompson, I. D., & Newmaster, S. G. (2013). Lichen conservation in heavily managed boreal forests. *Conservation Biology, 27*(5), 1020-1030.

Meinig, D. W. (1961). Goyder’s Line of Rainfall: The Role of a Geographic Concept in South Australian Land Policy and Agricultural Settlement

Agriculttural History, 135, 207-214.

Meining, D. W. (1962). *On the margins of the good earth: the South Australian wheat frontier 1869-1884*: Rand McNalley, Chicago.

Morley, S. F., & Gibson, M. (2005). Variation in cool temperate rainforest lichens of Victoria: implications for conservation. *Australasian Plant Conservation, 14*, 16.

Nascimbene, J., & Marini, L. (2010). Oak forest exploitation and black-locust invasion caused severe shifts in epiphytic lichen communities in Northern Italy. *Science of the Total Environment, 408*, 5506-5512.

Nascimbene, J., & Marini, L. (2015). Epiphytic lichen diversity along elevational gradients: biological traits reveal a complex response to water and energy. *Journal of Biogeography, 42*, 1222-1232.

Nascimbene, J., Nimis, P. L., & Ravera, S. (2013). Evaluating the conservation status of epiphytic lichens of Italy: A red list. *Plant Biosystems, 147*(4), 898-904. doi:10.1080/11263504.2012.748101

Nash, T. H. (1996). *Lichen Biology*: Cambridge University Press, Cambridge.

Nash, T. H. (2008). *Lichen Biology*: Cambridge Unversity Press, Cambridge.

Neilker, W. A., & Orvig, S. (1958). Evaporation and transpiration from an open lichen woodland surface. *International Association of Scientific Hydrololgy Assembly, 3*, 379-384.

Nicolle, D. (2013). *Native eucalypts of South Australia*: Dean Nicolle, Melrose Park, South Australia.

Nidumolu, U. D., Hayman, P. T., Howden, S. M., & Alexander, B. M. (2012). Re-evaluating the margin of the South Australian grain belt in a changing climate. *Climate Research, 51*, 249-260.

Nimis, P. L., & Martellos, S. (2001). Testing the predictivity of ecological indicator values. A comparison of real and "virtual" releves of lichen vegetation. *Plant Ecology, 157*, 165-172.

Nimis, P. L., Scheidegger, C., & Wolsele, P. A. (2002). *Monitoring with lichens - Monitoring lichens*: Kluwer Academic Publishers, Groningen, The Netherlands.

Nylander, M. W. (1866). Les lichens du Jardin du Luxembourg. *Bulletin de la Société Botanique de France, 13*, 364-372.

Nyrstar. (n.d). https://www.nyrstar.com/~/media/Files/N/Nyrstar/operations/melting/2018%20Fact%20Sheet%20-%20Port%20Pirie.pdf.

Örjan, F., Mats, N., & Marcin, C. (2008). Tree age is a key factor for the conservation of epiphytic lichens and bryophytes in beech forests. *Applied Vegetation Science, 12*, 93-106.

Ott, S. (1987). Sexual reproduction and development adaptations in *Xanthoria parietina*. *Nordic Journal of Botany, 7*, 219-228.

Ozturk, S., Oran, S., Guvenc, S., & Dalkiran, N. (2010). Analysis of the distribution of epiphytic lichens in the oriental beech *(Fagus Orientalis* Lipsky) along an altitudinal gradient in Uludag mountain, Bursa - Turkey. *Pakistan Journal Of Botany, 42*, 2661-2670.

Pallant, J. (2007). *SPSS survival manual, a step by step guide to data analysis using SPSS for windows*: 3rd edn. McGraw Hill, Sydney.

Parmesan, C., & Yohe, G. (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature, 421*, 37-42.

Paterson, D. R., Paterson, E. W., & Kenworthy, J. B. (1983). Physiological studies on temperate lichen species. *New Phytologist, 94*, 605-618.

Paul, A., Hauck, M., & Leuschner, C. (2009). Iron and phosphate uptake in epiphytic and saxicolous lichens differing in their pH requirements. *Environmental and Experimental Botany, 67*, 133-138.

Paulson, R. (1918). Notes on the ecology of lichens with special reference to Epping Forest. *Essex Nature, 18*, 276-286.

Pearson, R. G., & Dawson, T. P. (2003). Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography, 12*, 361-371.

Perkins, D. F., & Millar, R. O. (1987). Effects of airborne fluoride emissions near an aluminium works in Wales: Part 2 saxicolous lichens growing on rocks and walls. *Environmental Pollution, 48*, 185-196.

Perkins, D. F., Millar, R. O., & Neep, P. E. (1980). Accumulation of airborne fluoride by lichens in the vicinity of an aluminium reduction plant. *Environmental Pollution, 21*, 155-168.

Peterson, M. J. (1990). *Distribution and conservation of Houn pine*. Retrieved from Forestry Commission of Tasmania, Hobart:

Pharo, E. J., Beattie, A. J., & Pressey, R. L. (2000). Effectiveness of using vascular plants to select reserves for bryophytes and lichens. *Biological Conservation, 96*, 371-378.

Pinokiyo, A., Singh, K. P., & Singh, J. S. (2006). Leaf colonizing lichens: Their diversity, ecology and future prospects. *Current Science, 90*, 509-518.

Podger, F. D., Palzer, C., & Wardlaw, T. (1990). A guide to the Tasmanian distribution of *Phytopthora cinnamomi* and its effects on native vetegation. *Tasforests, 2*, 13-20.

Podger, F. D., Bayly-Stark, H. J., Brown, M. J., Delahunt, A., Kiernan, K., Kirkpatrick, J. B., . . . Richardson, A. M. (1990). *Report of the panel of experts of the Conservation Technical Working Group*: The Council, Hobart, Tasmania.

Potts, B. M. (1989). *Population variation and conservation status of rare Tasmanian endemic, eucalyptus cordata. Research report no. 4. Tasmanian Forest Research Council Inc., Hobart, Tasmania*. In (pp.

140).

Pouliot, A. M., & May, T. W. (2010). The third ‘F’ — fungi in Australian biodiversity conservation: actions, issues and initiatives. *Mycologia balcanica, 7*, 41-48

Purvis, O. W., Chimonides, J., Din, V., Erotokritou, L., Jeffries, T., Jones, G. C., . . . Spiro, B. (2003). Which factors are responsible for the changing lichen floras of London? *The Science of the total environment, 310*, 179-189.

Quedensley, T. S., & Pérez, M. V. (2011). *Ramalina mahoneyi,* a new corticolous lichen from a western Guatemalan cloud forest. *Lundellia, 14*, 3-7.

Queensland Government. (2018). SILO – Scientific information for land owners. Retrieved from silo.longpaddock.qld.gov.au

Quinn, J. M., Cooper, B. A., Davies-Colley, R. J., Rutherford, J. C., & Williamson, R. B. (1997). Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams, New Zealand. *Journal of Marine and Freshwater Research, 31*, 579-597.

Ranius, T., Johansson, P., Berg, N., & Niklasson, M. (2008). The influence of tree age and microhabitat quality on the occurrence of crustose lichens associated with old oaks. *Journal of Vegetation Science, 19*, 653-662.

Rhoades, H. (2014). Lichens on Trees – Treatment for Tree Lichen. Retrieved from http://www.gardeningknowhow.com/ornamental/trees/tgen/treatment-tree-lichen.htm

Rogers, R. W. (1972). Soil surface lichens in arid and subarid south-eastern Australia. III. The relationship between distribution and environment. *Australian Journal of Botany, 20*(3), 301-316.

Rogers, R. W. (1988). Succession and survival strategies in lichen populations on a palm trunk. *Journal of Ecology, 76*, 759-776.

Rogers, R. W. (1992). *Lichen ecology and biogeography - Flora of Australia*: AGPS Press, Canberra.

Rogers, R. W. (1995). Lichen succession on leaves of the rainforest shrub, *Capparis arborea (Capparaceae)*. *Australian Journal of Botany, 43*, 387-396.

Rogers, R. W., & Lange, R. T. (1971). Lichen populations on arid soil crusts around sheep watering places in South Australia. *Critical Reviews in Plant Sciences, 22*, 93-100.

Rogers, R. W., & Lange, R. T. (1972). Soil surface lichens in arid and subarid south-eastern Australia i. Introduction and floristics. *Australian Journal of Botany, 20*, 197-213.

Rolstad, J., & Rolstad, E. (1999). Does tree age predict the occurrence and abundance of Usnea longissima in multi-aged submontane Picea abies stands? *Lichenologist, 31*, 613-625.

Root, H. T., Jesse, E. D., Miller, & McCune, B. (2012). Biotic soil crust lichen diversity and conservation in shrub-steppe habitats of Oregon and Washington. *The Bryologist, 114*, 796-812.

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweigk, C., & J.A., P. (2003). Fingerprints of global warming on wild animals and plants. *Nature, 421*, 57-60.

Rosabal, D., Burgaz, A. R., & la Masa, R. D. (2010). Diversity and distribution of epiphytic macrolichens on tree trunks in two slopes of the montane rainforest of Gran Piedra, Santiago de Cuba. *The Bryologist, 113*, 313-321.

Rosabal, D., Burgaz, A. R., & Reyes, O. J. (2013). Substrate preferences and phorophyte specificity of corticolous lichens on five tree species of the montane rainforest of Gran Piedra, Santiago de Cuba. *The Bryologist, 116*, 113-121.

Rosabal, D., Burgaz, A. R., Altamirano, A., & Aragón, G. (2012). Differences in diversity of corticolous lichens between interior and edge of the Monte Barranca semi-deciduous forest, Santiago de Cuba. *The Bryologist, 115*, 333-340.

Rose, F. (1991). *The importance of old trees, including pollars, for lichens and bryophyte epiphytes. In: Read HJ (ed) Pollard and veteran tree management*: Corporation of London, London.

Ross, C., Fildes, S., & Millington, A. C. (2017). Land-Use and Land-Cover Change in the Páramo of South-Central Ecuador, 1979–2014. *Land, 6*, 46. doi:10.3390/land6030046

Ruggiero, M. A., Gordon, D. P., Orrell, T. M., Bailly, N., Bourgoin, T., & Brusca, R. C. (2015). A higher level classification of all living organisms. *PLoS One, 10*(4).

Russell, A. (2017). *The illustrated encyclopedia of trees in Britain and Europe*: Bloomsbury Press, London.

Scheidegger, C., & Werth, S. (2009). Conservation strategies for lichens: insights from population biology. *fungal biology reviews, 23*, 55-66.

Scheidegger, C., Frey, B., & Walser, J. (1998). Reintroduction and augmentation of populations of the endengered *Lobaria pulmonaria:* methods and concepts. In: Kondratyuk, S., Coppins, B.J. (Eds), *Lobarion Lichens as Indicators of the Primeval Forests of the Eastern Carpathians*. In: Phytosociocentre, Kiev.

Scotland, N., & Ludwig, S. (2002). *Deforestation, the timber trade and illegal logging*. Retrieved from EC Workshop on Forest Law Enforcement, Governanceand Trade, Brussels: http://www.unecefaoiufro.lsu.edu/responsible_trade/documents/2003-2006/rt03_062.pdf

Scott, G. A. M., Entwisle, T. J., May, T. W., & Stevens, G. N. (1997). *A conservation overview of Australian non-marine lichens, bryophytes, algae and fungi (lichens)*. In: Environment Australia, Canberra, Australia.

Seaward, M. (2000). Mosses, liverworts and lichens. *Transactions of the Lincolnshire Naturalists Union, 25*, 39-41.

Seaward, M. R. D. (1977). *Lichen Ecology*: Academic Press, London.

Seaward, M. R. D. (1993). Lichens and sulphur dioxide air pollution: field studies. *Environmental Review, 1*, 73-91.

Seaward, M. R. D. (1997). Major impacts made by lichens in biodeterioration processes. *International Biodeterioration & Biodegradation, 40*, 269-273.

Selva, S. B. (1994). Lichen diversity and stand continuity in the Northern hardwoods and spruce-fir forests of Northern New England and Western New Brunswick. *The Biologists, 97*, 424-429.

Sevgi, O., Cobanoglu, G., & Sevgi, E. (2016). Effect of forest habitat on the distribution of lichen species in Serif Yuksel research Forest, (Bolu, Turkey). *Pakistan Journal Of Botany, 48*, 581-588.

Singh, K. P., & Pinokiyo, A. (2008). New taxa of foliicolous lichens from eastern India. *The Lichenologist, 40*(1), 23–29.

Skye, E. (1979). Lichens as biological indicators of air pollution. *Phytopathol, 17*, 325-341.

Smith, A. L. (1921). *A handbook of the British lichens*: Cambridge University Press, Cambridge.

Snäll, T., Jr., R., & Rydin, H. (2003). Spatial occurrence and colonisations in patch-tracking metapopulations: Local conditions versus dispersal. *OIKOS, 103*, 566-578.

Snäll, T., Pennanen, J., Kivistö, L., & Hanski, I. (2005). Modelling epiphyte metapopulation dynamics in a dynamic forest landscape. *OIKOS, 109*(2), 209-222.

Stevenson, S. K., & Enns, K. A. (1993). *Quantifying arboreal lichens for habitat management: A review of methods. Report number: IWIFR-42. British Columbia. Ministry of Forests. Research Branch, Victoria, Canada*. Retrieved from

Synge, H. e. (1981). *The biological aspects of rare plant conservation*: John Wiley and Sons, Chichester.

Taylor, T. N., Hass, H., Remy, W., & Kero, H. (1995). The oldest fossil lichen. *Nature, 387*, 244.

Thomas, C. D., & Lennon, J. J. (1999). Birds extend their ranges northwards. *Nature, 399*, 213-213.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, C., . . . Williams, S. E. (2004). Extinction risk from climate change. *Nature, 427*, 145–148.

Thor, G. (1998). Red-listed lichens in Sweden: Habitats, threats, protection, and indicator value in boreal coniferous forests. *Biodiversity and Conservation, 7*, 59-72.

Thuiller, W., Lavorel, S., Araújo, M. B., Sykes, M. T., & Prentice, I. C. (2005). Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Science, 102*, 8245–8250.

Uliczka, H., & Angelstam, P. (1999). Occurrence of epiphytic macrolichens in relation to tree species and age in managed boreal forest. *Ecography, 22*, 396-405.

van Dobben, H. F., & ter Braak, C. J. F. (1999). Ranking of epiphytic lichen sensitivity to air pollution using survey data: A comparison of indicator scales. *The Lichenologist, 31*(1), 27-39.

van Herk, C. M. (2001). Bark pH and susceptibility to toxic air pollutants as independent causes of changes in epiphytic lichen composition in space and time. *The Lichenologist, 33*(5), 419-441.

van Herk, C. M., Aptroot, A., & van Dobben, H. F. (2002). Long-term monitoring in The Netherlands suggests that lichens respond to global warming. *The Lichenologist, 34*(2), 141-154.

Vanderpoorten, A., Engels, P., & Sotiaux, A. (2004). Trends in diversity and abundance of obligate epiphytic bryophytes in a highly managed landscape. *Ecology, 27*, 419-441.

Viles, H. A. (1988). *Biogeomorphology*: John Wiley & Sons, Chichester.

Vinayaka, K. S., Shravanakumar, S., Udupa, S. K., & Krishnamurthy, Y. L. (2011). Diversity of epiphytic lichens and evaluation of important host species exploited by them in tropical semi-evergreen and deciduous forests of Koppa, central western Ghats, India. *The Asian and Australasian Journal of Plant Science and Biotechnology, 5*, 62-66.

Vondrak, J., Khodosovtsev, A. Y., Soun, J., & Vondrakova, J. (2012). Two new European species from the heterogenous *Caloplaca holocarpa* group *(Teloschistaceae)*. *The Lichenologist, 44*, 73-89.

Warren, M. S., Hill, J. K., Thomas, J. A., Asher, J., Fox, R., Huntley, B., . . . Thomas, C. D. (2001). Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature, 414*, 65-69.

Wheater, C. P., & Cook, P. A. (2000). *Using statisctics to understand the environment*: Routledge, London.

Williams, M. (1976). Planned and unplanned changes in marginal lands of South Australia. *Australian Geographer, 13*, 271-281.

Wirth, V. (1995). *Die Flechten Baden-Würtembergs. Verbreitungsatlas*: Ulmer, Stuttgart.

Wit, D. A. (1976). *Epiphytic lichens and air pollution in The Netherlands* (Vol.

5): Vaduz, Germany.

Wolseley, P. A., & Aguirre-Hudson, B. (1997). The ecology and distribution of lichens in tropical deciduous and evergreen forests of northern Thailand. *Journal of Biogeography, 24*, 327-343.

Working Group for Rainforest Conservation. (1990). *Recommended areas for protection of rainforest in Tasmania*: Forestry Commission, Tasmania.

Yarranton, G. A. (1972). Distribution and succession of epiphytic lichens on black spruce near Cochrane, Ontario. *The Bryologist, 75*, 462-480.

Yeshitela, K., Fischer, E., Killmann, D., & Serusiaux, E. (2009). *Aspidothelium hirsutum* (Thelenellaceae) and *Caprettia goderei* (Monoblastiaceae), two new species of foliicolous lichens from Ethiopia and Kenya. *The Bryologist, 112*, 850-855.